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Biological Services Program

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Effect of Peat Mining on Fish and Other Aquatic Organisms in the Upper Midwest

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May 1981

EFFECT OF PEAT MINING ON FISH AND OTHER AQUATIC ORGANISMS IN THE UPPER MIDWEST

by

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INTRODUCTION

Peat is a term used to classify a set of materials formed of partially decomposed organic matter and inorganic minerals that have accumulated in a water saturated environment. Peat has two major commercial uses in the portion of the world where it occurs: (1) as a soil conditioner and (2) as a source of energy. Peat has been harvested both as a soil additive and for energy in the United Kingdom, Russia, and the Scandinavian Countries for many years. Dried peat is burned directly for heat, is coked for industrial use, and fuels power plants for generating electricity.

In the United States peat has been used primarily for horticultural purposes. Peat is harvested in relatively small commercial developments (10-500 acres), using techniques adapted from Europe, for the production of "peat moss" and potting soil. The recent investigations of alternate energy sources and increased prices for fuels has produced interest in the United States in peat as an energy source.

The United States has one of the world's largest holdings of peat resources, potentially equivalent in energy yield to 240 billion barrels of oil (U.S. Department of Energy, 1979). The U.S. Department of Energy is cooperating with six states having major peat deposits to locate, map, and inventory those resources. These states are Alaska, Minnesota, Michigan, Maine, North Carolina, and South Carolina.

A relatively large, private peat-for-fuel project is being developed in North Carolina. First Colony Farms of Creswell, North Carolina owns over 100,000 acres of harvestable peat reserves in the northeastern part of the state. First Colony Farms has received permission from the North Carolina Department of Natural Resources and Community Development to mine about 15,000 acres of the peatland. Negotiations are being conducted with several utility groups for supplying peat in order to fuel an electrical generating station.

The possibility of a large peat-synfuel project is being studied in Minnesota. Minnesota Gas Company (Minnegasco), in cooperation with several private and public agencies, is examining the feasibility of converting peat into pipeline quality gas. As part of the project, Minnegasco has proposed to lease about 200,000 acres of state-owned peatlands in north central Minnesota for mining.

Very few studies have been conducted on the ecology and hydrology of peatlands. Hence, there is little baseline data from which to predict the environmental consequences of peatland developments. In response, the

Minnesota Legislature has funded surveys of the hydrology, water quality, mammalian and herpetological fauna, bird life, and vegetation of peatlands. Surveys of the aquatic fauna of peatlands, however, were not funded.

The purpose of this study is to review the literature pertinent to peatlands and peat mining in order to determine the effects of peat mining on aquatic animal life. The specific goals of this paper are to: (1) describe the peatland aquatic habitat and the fauna therein, (2) compare existing and proposed peat mining techniques, (3) evaluate the effects of peat mining on the aquatic fauna, (4) suggest possible mitigation of undesirable effects, and (5) identify important data gaps in the literature.

CHARACTERIZATION OF PEATLAND AQUATIC FAUNA

THE PEATLAND HABITAT

Peatland Formation

Peatlands are a set of areas in which the rate of organic production exceeds organic respiration and decomposition rates over time. These areas are variable with respect to structure, biotic composition, appearance, and rate of accumulation of peat. Peatlands are dynamic ecological systems which result from interactions among water, geological factors, climate, biological factors, and time (Moore and Bellamy, 1974).

The peatlands of the Upper Midwest were formed by two different types of ecological processes, hydrarch succession and paludification. Hydrarch succession, reviewed by Moore and Bellamy (1974), is the process of lake basins becoming filled by the continuous deposition of undecomposed aquatic vegetation (peat). Table 1 summarizes the distribution of peat deposits in the United States.

The corrosion and deposition effects of glaciation in the Upper Midwest provided an abundance of lake basins in which conditions are suitable for hydrarch succession. These lakes are characterized by a shallow average depth and extensive development of littoral vegetation. In such lakes the littoral vegetation and associated epiphytic flora typically dominate the system productivity (Wetzel, 1975). Over time, the accumulation of organic matter displaces standing water and may modify the lacustrine environment to favor the development of a closed vegetation cover usually dominated by reeds and sedges (Figure 1). The organic deposition of futher successional stages (grasses, for example) may exceed the height of the mean water table, allowing the invasion of terrestrial plant species. Basins receiving low inputs of plant nutrients may instead develop a dominant cover of bryophytes, particularly Sphagnum species, which will affect local water quality and quantity.

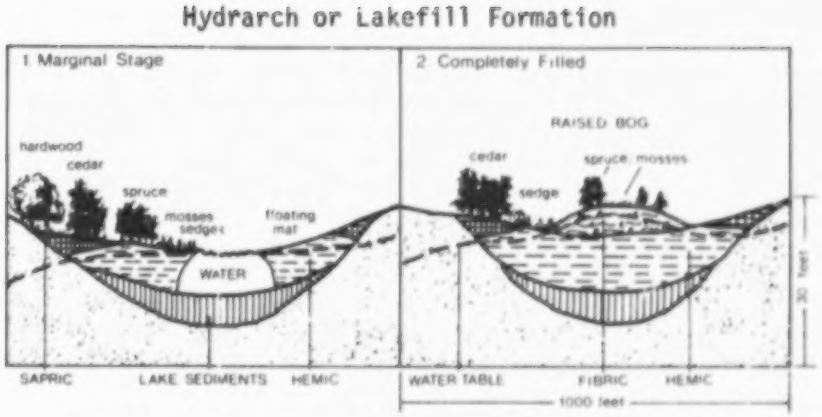
Whereas hydrarch succession occurs in depressions and does not affect adjacent uplands, paludification is a process of peatland expansion in which the wetland may move uphill into upland topography (Figure 1). Peatland vegetation, especially Sphagnum species, tends to slow and retain relatively large quantities of water. Therefore, lake-filled (hydrarch) peatlands may tend to raise the water table of immediately adjacent uplands, creating new habitat for peatland plant species. Thus, some peatlands tend to increase in area over time.

Table 1. Distribution of Peat Reserves in the United States[a]

Geographic Area	Estimated Reserves		Potential Energy Available Quads (10^{15} Btu)
	Acres (millions)	Quantity (billion tons)	
Alaska	27.0	61.7	741
Minnesota	7.2	16.5	198
Michigan	4.5	10.3	123
Florida	3.0	6.9	82
Wisconsin	2.8	6.4	77
Louisiana	1.8	4.1	49
North Carolina	1.2	2.7	33
Maine	0.77	1.8	21
New York	0.65	1.5	18
Hawaii	0.48	1.1	13
Georgia	0.43	1.0	12
Indiana	.38	.9	10
Massachusetts	.35	.8	9.5
Virginia	.31	.7	8.6
Washington	.20	.5	5.5
All other states	1.5	3.4	41
Total	52.58	120.3	1443

[a]Punwani and Rader, 1978 (originally compiled by Dr. Rouse Farnam).

In similar fashion, Sphagnum peatlands tend to raise the water table within the peatland itself, allowing vertical as well as horizontal expansion by paludification. Such Sphagnum peatlands (raised bogs) are typically dome shaped and occur on top of reed-sedge peat deposits. The water table within the dome may become raised to the extent that is isolated from the regional ground water supply (Boelter and Verry, 1977).



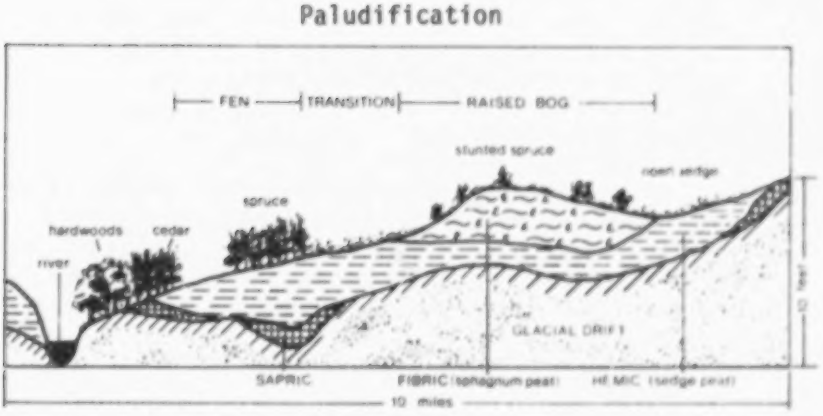


Figure 1. Processes of peatland formation (courtesy of Minnesota Department of Natural Resources).

Peatland - Water Relationships

Peatlands occur in the Upper Midwest in part because the decomposition of organic matter is retarded by saturation with water. Peat is a biologically and chemically active set of materials which interacts with water in a number of ways. The peatland water quality and quantity relationships most pertinent to the aquatic biota are discussed below.

Peatland Classification

Peatlands can be classified according to many criteria, but the functional classification most useful for this study is based on the peatland's water source. In this scheme there are two extreme types of peatland: (1) ombrotrophic peatlands, or bogs which receive their water supply from precipitation, and (2) Mineratrophic peatlands, or fens which derive their water supply from ground water. Peatlands, of course, may represent intermediate cases, receiving water from both sources.

This classification is useful because a peatland's water source profoundly influences the nature of the ecosystem. Ombrotrophic bogs are hydrologically isolated from the ground water system and the entire water budget is due to precipitation on an encapsulated watershed. Precipitation is ion-poor, therefore the site itself is ion-poor (Boelter and Verry, 1977). Such peatlands are typically quite acidic, small in size, and dominated by a characteristic wetland flora including the genera Sphagnum, Vaccinium, Ledum, Kalmia, and Chamaedaphne (Bay, 1967).

Mineratrophic fens receive most of their water supply from ground water and, as a consequence, are ion-rich. These peatlands are more alkaline than bogs, are variable in size, and may be dominated by flora of the genera Carex, Calamagrostis, Salix, Cornus, and Iris (Bay, 1967).

Water Quality

Peatland water chemistry depends on the kind and amount of water supplied, the distance water travels through the peatland, and regional and surficial geology. In general, peatlands formed over Canadian Shield rocks, in sandy outwash plains, or over acidic soils tend toward the ombrotrophic state. Those that form over Niagra limestones or neutral glacial tills with exchangeable bases tend toward mineratrophic status (Likens et al., 1977; Ludwig et al., 1980). In Minnesota peatlands lie over glacial materials.

Bog waters typically have pH values of 3 to 4, specific conductance of less than 15 mhos, and a calcium concentration of less than 5 mg/l (Table 1). Nitrogen and phosphorus concentrations may be relatively high. The range of pH values found in bogs is lower than that in fens because Sphagnum species control acidity through cation exchange reactions (Clymo, 1964). The predominant cation in bogs is hydrogen and the predominant anion is sulfate (Boelter and Verry, 1977).

Fens generally have water pH values of 6 to 8, specific conductance of more than 74 mhos, and calcium concentrations exceeding 15 mg/l (Table 2). The predominant cation in fens is calcium and the predominant anion is bicarbonate (Boelter and Verry, 1977). Mineratrophic fens may grade into ombrotrophic areas (transition zones) and, in general, have a wider range of chemical values because of variation in the kind and amount of ground water present. Generalized ranges for key water quality parameters in different classes of peatlands are presented in Table 2.

Streams draining bogs and fens are chemically influenced by peat and tend to reflect the prevailing water chemistry of the peatland (Lee et al, 1971; Verry, 1975). This effect is most pronounced in the immediate vicinity of the peatland and becomes diminished downstream due to dilution and buffering from other water sources.

Water Quantity

The water yield characteristics of peatlands are related to climate, physical properties of peat, vegetation, and topography (Brooks and Predmore, 1978). Temporal and spatial differences in precipitation can obviously affect local hydrology. On a somewhat larger scale, climate also influences the rate of evapotranspiration losses.

The water retention characteristics and rate of water movement in peat soils are strongly related to the degree of decomposition and bulk density of the peat (Boelter, 1969). Peat soils are characterized as fibric, hemic, or sapric with respect to these characteristics. Fibric soils are the least decomposed and have the lowest bulk density and largest average pore size among these types. Sapric soils are the most highly decomposed and have the highest bulk density and smallest average pore size. As a result, hydraulic conductivity is highest in fibric soils and lowest in sapric soils. Hemic peats are intermediate in character between these extremes. In short, water drains faster and more completely from fibric peats, which usually comprise the upper peatland soil horizons, than from the deeper sapric horizons (Boelter, 1969; Boelter and Verry, 1977; Brooks and Predmore, 1978).

Peatland vegetation can influence the hydrologic system. Vegetation actively transpires subsurface water and intercepts precipitation which subsequently evaporates. Both of these processes represent losses to potential runoff or ground water supplies.

Although most peatlands exhibit relatively flat topography, micro-relief features may influence runoff and infiltration processes (Dooge, 1975). Runoff and streamflow from both ombrotrophic or mineratrophic peatlands is directly related to the height of the water table. Greater discharges occur at higher water levels because soil moisture storage capacity is reduced when the water table is high. Increased water levels may create greater hydraulic gradients. In addition, higher water tables typically lie in the least decomposed (fibric) surface peats which exhibit greater hydraulic conductivity (Brooks and Predmore, 1978).

Table 2. Relative Ranges of Important Water Quality Parameters in Upper Midwest Peatlands[a]

Parameter	Peatland Classification		
	Bog	Transition	Fen
pH	3-4	4-6	6-8
Calcium (mg/l)	<1-7	4-20	15->100
Turbidity	Moderate to Low	Moderate	Low
Color	High	Moderate	Low
Nitrogen	High	Variable	Low
Phosphorus	High	Variable	Low
Iron (mg/l)	0.5-10	<2	<0.5
Specific conductance (μ mhos)	10-15	30-90	75-400
Exchangeable cations	>90% H^+	<50% H^+	1% H^+
Dissolved oxygen	often anaerobic	may be anaerobic	usually aerobic

[a]Data generalized from Bay (1967), Heinselman (1970), Hofstetter (1969), and Verry (1975).

The pattern of seasonal variation in water levels differs between bogs and fens because of the influence of ground water supplies on fens. About two-thirds of the annual water yield from Minnesota bogs occurs between late March and June 1 (Bay, 1969; Verry and Boelter, 1975). During summer, water yield from bogs decreases and streamflow may cease (Heinselman, 1963). Although bogs do not regulate annual water by releasing stored water during dry periods (Bay, 1969; Boelter and Verry, 1977), some delay of snowmelt and stormflow occurs due to the peatlands' relatively flat topography and short-term storage capability (Boelter and Verry, 1977).

The water balance of fens has not been studied as thoroughly as that of bogs, probably because of difficulties in measuring system inputs and outputs (Brooks and Predmore, 1978). Fens serve as discharges for the regional ground water system and have a more uniform seasonal distribution of water yield than bogs. In Minnesota fens, streamflow peaks in the spring, followed by a gradual decrease in flow throughout the year (Verry and Boelter, 1975). Fens may provide short term water retention similar to bogs (Brooks and Predmore, 1978).

THE PEATLAND AQUATIC FAUNA

The following sections discuss the distribution, life histories, and special requirements of fish and other major aquatic fauna found in the major peatland surface waters in the Upper Midwest. The geographical relationships between known peat deposits and major surface waters are delineated in Figures 2, 3, and 4.

Fisheries

The fishery resources of surface waters in the Upper Midwest peatlands region are valuable and diverse. A wide variety of habitat types occur within the region including springs, headwaters, coldwater and warmwater streams, large rivers, lakes, and impoundments which support a rich assemblage of fish species. The primary value of these fisheries lies in their recreational usage. Extensive sport fisheries exist for a number of species and management activities in the region are targeted principally for angling. Commercial fishing also occurs, adding to the value of these resources. Three categories of fish habitats are related to peatlands: (1) waters within peatlands, (2) watercourses draining peatlands, and (3) bodies of water in the region where peatlands occur. The following sections discuss the most important taxa of fisheries associated with these type of habitats. Table 3 summarizes the species utilizing waters within peatlands *per se*.

Esocidae (Pike Family)

The representatives of the Esocidae known to occur in the Upper Midwest peatlands region are the northern pike, grass pickerel, and muskellunge. The northern pike is common to abundant in most waters of the Upper Midwest peatlands region. Despite being considered a nuisance in some areas, particularly where it displaces the muskellunge, the northern pike is a valuable game species throughout the region. This species is harvested commercially by native Americans from inland waters and some areas of the Great Lakes.

Northern pike inhabit cool to moderately warm lakes, ponds, and sluggish streams (Hubbs and Lagler, 1974). This species is also abundant in most clear, cold, oligotrophic lakes in the region (Eddy and Surber, 1960). Drainage lakes with inlet streams are generally more productive of northern pike than seepage lakes (Threinen et al., 1966).

A - Roseau River

B - South Fork

C - Agassiz Pool

D - Warroad River - East Branch

E - Winter Road River

F - Rapid River System

G - Big Fork River

H - Little Fork River

I - Vermilion River

J - Upper and Lower Red Lakes

K - Cass Lake

L - Lake Winnibigoshish

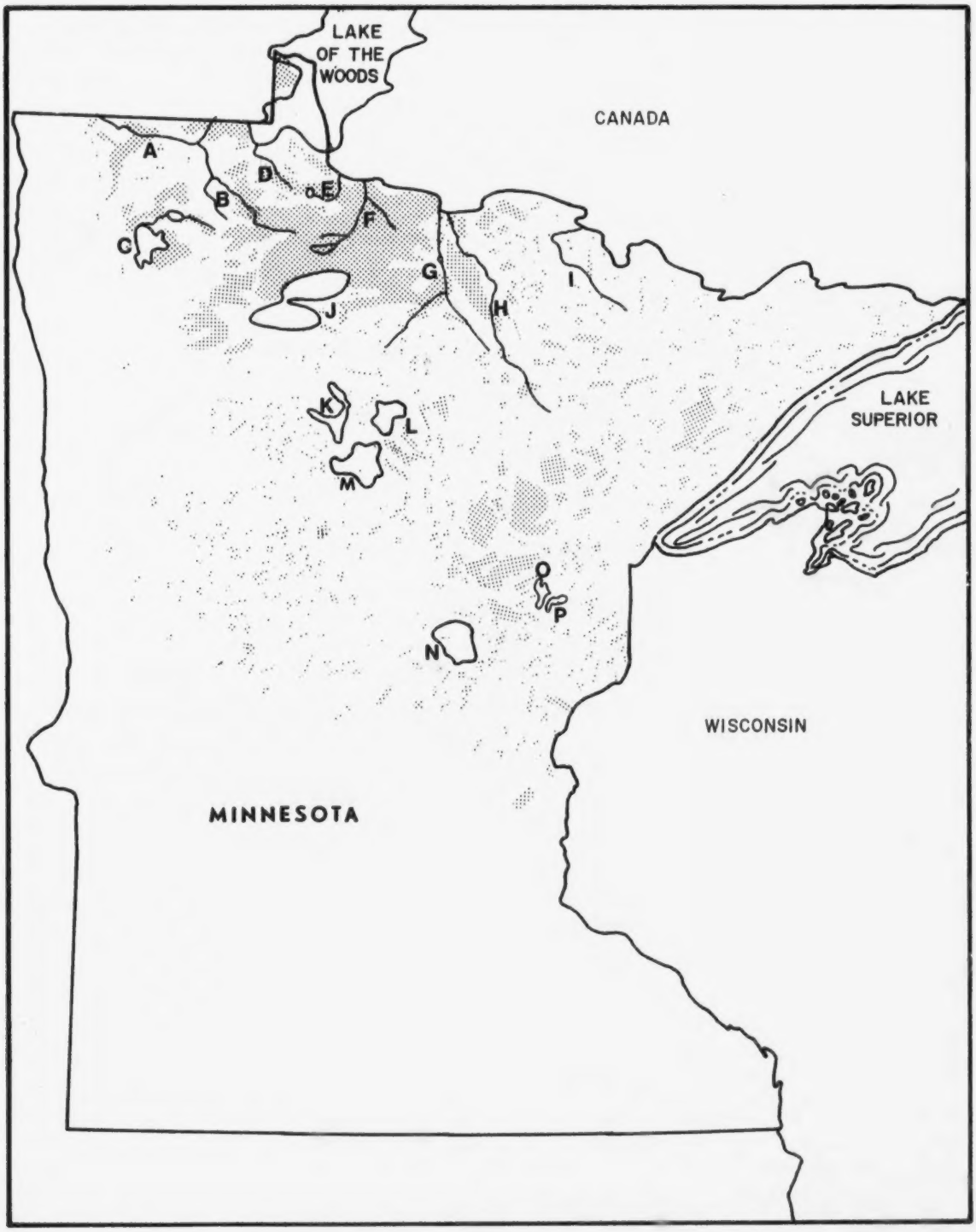
M - Leech Lake

N - Mille Lacs Lake

O - Big Sandy Lake

P - Lake Minnewawa

Figure 2. Major peat deposits (shaded areas) and associated surface waters of Minnesota.


LAKE
OF THE
WOODS
CANADA
A
B
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G
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I
J
K
L
M
N
P
LAKE
SUPERIOR
WISCONSIN
MINNESOTA

A - St. Croix River

B - Mississippi River

C - Big Eau Pleine River and Reservoir

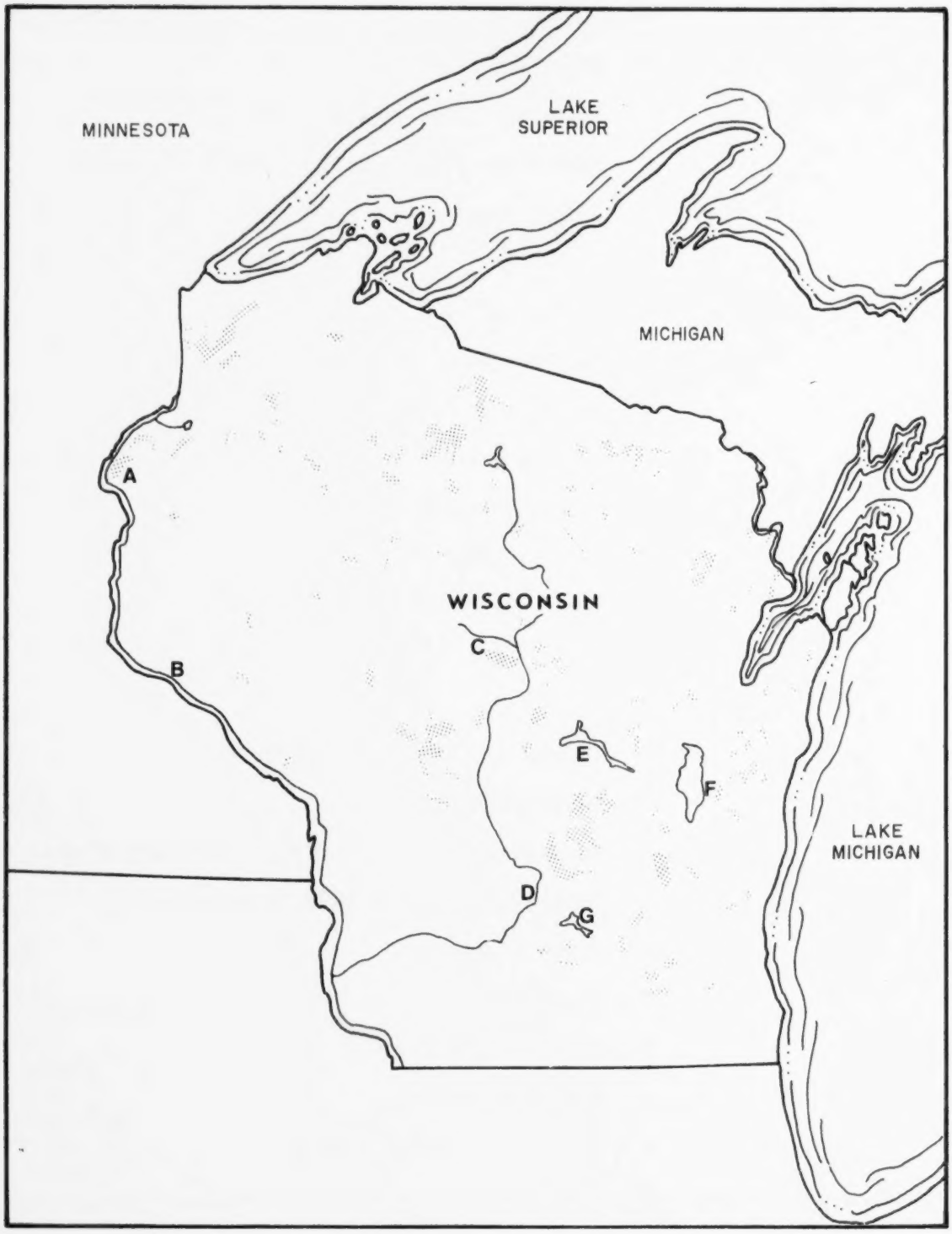
D - Wisconsin River

E - Poygan Lake

F - Lake Winnebago

G - Lake Mendota

Figure 3. Major peat deposits (shaded areas) and associated surface waters in Wisconsin.


MINNESOTA
LAKE
SUPERIOR
MICHIGAN
A
WISCONSIN
C
B
E
F
LAKE
MICHIGAN
D
G

A - Whitefish River - West Branch

B - Whitefish River - East Branch

C - Manistique River - West Branch

D - Driggs River

E - Fox River

F - Manistique Lake

G - Two Hearted River

H - Tahquamenon River

I - Munuscong River

J - Lake Charlevoix

K - Walloon Lake

L - Burt Lake

M - Mullet Lake

N - Black Lake

O - Thunder Bay River - North Branch

P - AuSable River

Q - North Branch AuSable and Mid Branch Big Rivers

R - Thunder Bay River - South Branch

S - Higgins Lake

T - Houghton Lake

U - Tittabawassee River

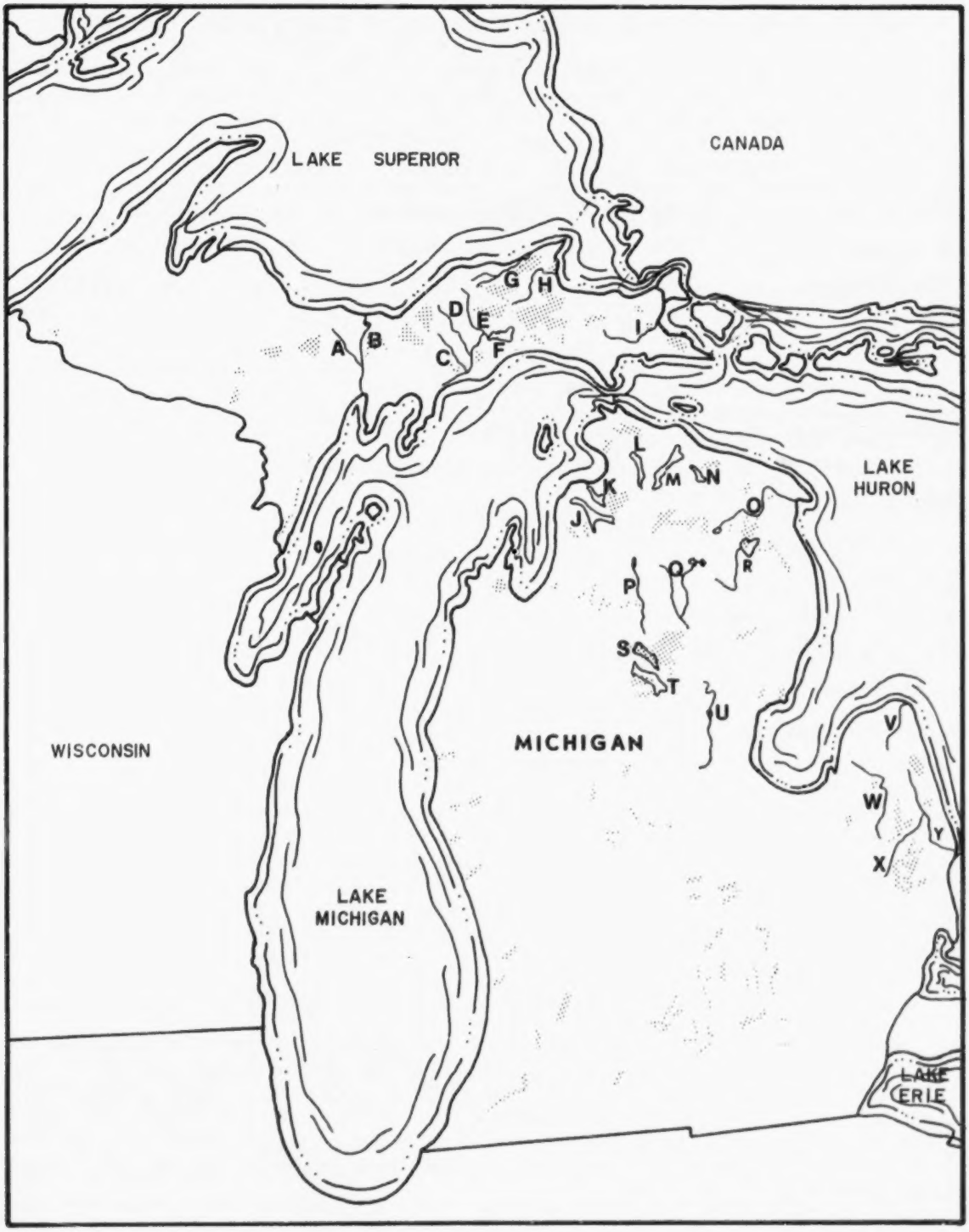
V - Willow River

W - Cass River - South Branch

X - Elk River

Y - Black River

Figure 4. Major peat deposits (shaded areas) and associated surface waters in Michigan.


LAKE SUPERIOR
CANADA
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WISCONSIN
MICHIGAN
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Table 3. Summary of Fish Species Occurring in Waters Within Peatlands

Species	Comments
Northern pike	Peatlands provide spawning and nursery habitat
Muskellunge	Peatlands provide spawning and nursery habitat
Grass pickerel	Spawning and nursery habitat in Southern Wisconsin
Walleye	Not preferred habitat
Bluegill	Not preferred habitat
Banded killifish	
Starhead topminnow[a]	Southern Wisconsin and Southern Michigan
Blackstripe topminnow	Southern Wisconsin and Southern Michigan
Brook stickleback	
Central mudminnow	
Pearl dace	
Northern redbelly dace	
Finescale dace	
Brassy minnow	
Fathead minnow	
Bullhead	Not preferred habitat

[a]Endangered species - Wisconsin (Wisconsin DNR, 1979).

Spawning occurs in early spring, when northern pike migrate upstream, or from lakes into small streams or marshes. Large marshy areas having streams flowing through them are particularly favored for spawning. Eggs are randomly deposited over flooded emergent vegetation. Fry tend to remain in these flooded marshes until food requirements or receding water levels force them into permanent water. Fens may be used as both spawning and nursery areas (Szmania, 1973).

Northern pike are voracious predators, consuming fish and a variety of other organisms. Yellow perch and suckers are the most frequent prey (Threinen et al., 1966). Northern pike are sight feeders and, as such, are intolerant of excessive turbidity. This species is quite tolerant of low dissolved oxygen concentrations, however, often surviving winter kill conditions fatal to carp and bullhead. High, stable spring water levels are important to pike production. Reductions of water levels prior to spawning may prevent adults from utilizing prime spawning areas and rapid decreases in water levels after spawning may leave eggs or fry stranded in marsh areas (Threinen et al., 1966).

Grass pickerel are not believed to occur in Minnesota (Eddy and Surber, 1960) and their local range is limited to the southern portions of Wisconsin and Michigan (Kleinert and Mraz, 1966; Hubbs and Lagler, 1970). Muskellunge are also restricted in range. They occur in the upper Mississippi River drainage and Lake of the Woods in Minnesota (Eddy and Surber, 1960), in the headwater lakes and streams of the Chippewa, Amnicon, Flambeau, and Wisconsin Rivers of Wisconsin (Oehmcke et al., 1968), and sporadically throughout the Great Lakes drainages of Michigan. Grass pickerel are small, seldom exceeding 12 inches in length, and are of no significant economic value. Muskellunge are prized game fish and their distribution has been increased by fishery management stocking programs.

In streams, both species prefer quiet, weedy areas having little or no current flow. In lakes, shallow, weedy areas are preferred with the muskellunge frequenting somewhat deeper areas than the grass pickerel. Both species are tolerant of low oxygen concentrations, but are intolerant of turbidity (Klienert and Mraz, 1966; Oehmcke et al., 1968).

As with northern pike, both species migrate to spawn, moving upstream in river systems or into shallow, weedy, muck-bottomed bays of lakes. Grass pickerel are very early spawners, arriving in spawning areas shortly after spring ice-out. Muskellunge spawn somewhat later, usually from late April through May. Successful spawning is related to access to suitable spawning areas and stable weather conditions. High water in spring allows these species access to preferred spawning sites. Poor reproductive success may occur in years of low springtime water levels. Both of these species utilize waters in peatlands for spawning and nursery areas in Wisconsin (Kleinert and Mraz, 1966; Oehmcke et al., 1968).

Percidae (Perch Family)

The Percidae are represented in the peatlands region by walleye, yellow perch, and the darters. Sauger inhabit water bodies in areas where peatlands occur, but are not known to inhabit peatlands or peatland drainges.

The walleye is common to most major watercourses in the peatlands region and is abundant in many area lakes and streams. The walleye is one of the most valuable game species, and has received considerable management effort. Once a major commercial species, the walleye is now harvested commercially in a few waters, primarily by native Americans.

Walleye are widely distributed and abundant in Minnesota, particularly in the lakes and streams of the Mississippi drainage, Red Lakes, and Lake of the Woods (Eddy and Surber, 1960). Walleye are also common to most major drainage systems in Wisconsin and they have been introduced into many waters beyond their native distribution (Niemuth et al, 1972). Greatest abundance occurs in waters of the St. Croix, Chippewa, Black, Wisconsin, Wolf, and Fox River drainages. Walleye are common in Michigan in major streams, larger inland lakes, and bays of the Great Lakes.

Although walleye occur in all types of lakes, including bog lakes, they reach their greatest abundance in larger streams and large, open lakes with moderately fertile water (Niemuth et al., 1972). This species perfers clear water with a gravel, rock, sand or hard clay bottom, and is intolerant of excessive turbidity (Becker, 1976). Therefore, waters occurring in peatlands represent marginal rather than preferred walleye habitat.

Walleye begin their spawning migration immediately after ice-out, and spawning usually occurs from mid-April through mid-May in the Upper Midwest. Spawning requires areas of moving water and takes place in streams or along open lake shores subject to wave action. Eggs are typically deposited over rocky, gravelly, or sandy substrates. Walleye in Wisconsin's Wolf River, however, spawn over flooded marsh vegetation. In Tamas Lake, spawning occurs over the tangled root masses of bog vegetation (Niemuth et al., 1972).

Young walleye feed initially on crustaceans, then insect larvae, and finally fish. Adults are primarily piscivorous, although they will also take larger aquatic insects. Major prey of walleye include yellow perch, freshwater drum, emerald shiner, trout-perch, and gizzard shad.

Walleye production is closely related to favorable spring weather and stable water levels. High, stable water levels are associated with strong year classes. Rapid or large decreases in water levels may leave eggs stranded above the water line. Incubating walleye eggs are vulnerable to being smothered by depositions of sediment or plant material (Niemuth et al., 1972).

The yellow perch is a popular game fish and valuable food species. Perch are commercially harvested from both inland lakes and the Great Lakes. The yellow perch is one of the most widely distributed species in the three state peatland region. This species is found in most regional lakes and backwaters and impoundments of larger rivers (Herman et al., 1978), but are seldom found in small streams (Eddy and Surber, 1960). Perch are abundant and commercially harvested in Red Lakes, Minnesota which receive large drainage inputs from peatlands. Yellow perch prefer waters of moderate temperature, and reach their greatest abundance in fertile waters having high phytoplankton standing crops and dense bottom fauna populations (Herman et al., 1978).

Spawning occurs in April or May at water temperatures between 7.2 - 11.1^{o}C (Herman et al., 1978). At this time, adults move into areas of shallow water and deposit gelatinous ribbons of eggs on submerged plants, fallen trees, or other debris (Becker, 1976). Growth of yellow perch is highly variable

depending on environmental conditions and population density. Perch consume a wide variety of aquatic organisms including crustaceans, insect larvae, crayfish, and small fish. Yellow perch represent valuable forage for such predatory game species as walleye, northern pike, and muskellunge (Becker, 1976). Yellow perch are tolerant of low oxygen concentrations, often surviving conditions fatal to bluegill, large-mouth bass, and walleye (Herman et al., 1978).

Seventeen species of darters occur in the Upper Midwest peatlands region: the river, blackside, Johnny, bluntnose, banded, mud, rainbow, Iowa, fantail, slenderhead, gilt, western sand, eastern sand, least, crystal, and greenside darters and the logperch. The principal value of darters is as forage, but three species, the crystal, bluntnose, and gilt darters are considered endangered in Michigan (Michigan DNR, 1979). Two species have been given threatened status, the mud darter in Wisconsin and the eastern sand darter in Michigan (Wisconsin DNR, 1979; Michigan DNR, 1979). The threatened and endangered aquatic species in the Upper Midwest region are identified in Table 4.

Darters spawn in spring over various substrate types with the male remaining to guard the nesting site. All species of darters are primarily benthic feeders, consuming chironomid larvae and other invertebrates (Scott and Crossman, 1973).

The distributions of darters are poorly known. Most darter species prefer clear, running water with a sand or gravel substrate, although a few species such as the Iowa and Johnny darters are also found in lakes (Becker, 1976). All darters require highly oxygenated water and are intolerant of siltation and turbidity. Because of this intolerance to environmental stress and the legally protected status of some darters, surveys of watercourses traversing or draining peatlands for these species are advisable prior to peatland disturbance.

Centrarchidae (Sunfish Family)

The Centrarchidae are represented in the Upper Midwest peatlands region by the smallmouth bass, largemouth bass, black and white crappies, and eight species of the genera Lepomis and Ambloplites. The bluegill is the only Centrarchid known to frequent waters within peatlands. Several members of the sunfish family are capable of inhabiting watercourses downstream from peatlands.

The smallmouth bass is one of the most highly sought recreational game fish in the peatlands area. Smallmouth bass inhabit most of the cool, flowing streams and large, clear lakes over 20 feet in depth in the Upper Midwest (Becker, 1976). This species is most abundant in lakes with rooted aquatic vegetation and clean, gravel shores.

Table 4. Summary of State Threatened and Endangered Aquatic Fauna in the Upper Midwest[a]

Species		Status[b]
	FISHES	
Acipenser fulvescens	Lake sturgeon	T - MI, T - MN
Ammocryta asprella	Crystal darter	E - WI
Ammocryta pullucida	Eastern sand darter	T - MI
Clinostomus elongatus	Redside dace	T - MI
Coregonus alpenae	Longjaw cisco	E - MI
Coregonus johannae	Deepwater cisco	E - MI
Coregonus nigripinnis	Blackfin cisco	E - MI
Coregonus reighardi	Shortnose cisco	E - MI
Coregonus zenithicus	Shortjaw cisco	E - MI
Coregonus artedii	Cisco	T - MI
Coregonus hoyi	Bloater	T - MI
Coregonus kiyi	Kiyi	T - MI
Cycleptus elongatus	Blue sucker	T - WI, T - MN
Dionda nublia	Ozark minnow	T - WI
Erimyzon oblongus	Creek chub sucker	T - MI
Etheostoma chlorosomum	Bluntnose darter	E - WI
Etheostoma asprigene	Mud darter	T - WI
Fundulus notti[c]	Starhead topminnow	E - WI
Hiodon alosoides	Goldeye	T - WI
Hybopsis amblops	Bigeye chub	T - MI
Hybopsis x-punctata	Gravel chub	E - WI, T - MN
Hybopsis aestivalis	Speckled chub	T - WI
Ictiobus niger	Black buffalo	T - WI
Lepomis megalotis	Longear sunfish	T - WI
Moxostoma carinatum	River redhorse	T - MI, T - WI

continued

Table 4 (continued)

Species		Status
Notropis amnis	Pallid shiner	T - WI
Notropis anogenus	Pugnose shiner	T - WI
Notropis chrysocephalus	Striped shiner	E - WI
Notropis photogenis	Silver shiner	T - MI
Noturus stigmosus	Northern madtom	E - MI
Noturus exilis	Slender madtom	E - WI
Percina evides	Gilt darter	E - WI
Stizostedion vitreum glaucum	Blue pike	E - MI
Thoxinus erythrogaster	Southern redbelly dace	T - MI
	MOLLUSKS	
Actinonaias cavinata		T - MN
Actinonaias ellipsiformis		T - MI
Anguispira kochi		T - MI
Anodonta subgibbosa		T - MI
Bulimnea megasoma		T - MI
Cyclonaias tuberculata		T - MI, E - MN
Discus patulus		T - MI
Dysnomia triquetra		T - MI
Elliptio complanatus		T - MI
Elliptio crassidens		E - MN
Ellipsaria lineolata		T - MN
Fontigens nickliniana		T - MI
Fusconaia ebena		E - MN
Haplotrema concavum		T - MI
Lampsilis higginsi	Higgins Eye Pearly Mussel	E - WI, E - MN
Lampsilis fasciola		T - MI
Lampsilis teres		E - MN

continued

Table 4 (continued)

Species		Status
Lasmigona co[illegible]a		T - MN
Mesodon sayanus		T - MI
Mesodon elevatus		T - MI
Mesomphix cupreus		T - MI
Obovaria leibii		E - MI
Plethobasus cyphus		E - MN
Pleurobema clava		T - MI
Pomatiopsis cincinnatiensis		T - MI
Potamilus capax		E - MN
Probythinella lacustris		T - MI
Quadrula metanevra		T - MN
Simpsoniconcha ambigua		E - MI
Triodopsis denotata		T - MI
Tritogonia verrucosa		E - MN
Zoogenetes harpa		T - MI
	AMPHIBIANS	
Ambystoma maculatum	Spotted salamander	T - WI
Ambystoma tremblayi	Tremblay's salamander	T - WI
Rana pipiens burnsii	Burns' leopard frog	T - WI
Rana palustris	Pickerel frog	T - WI
	REPTILES	
Clemmys insculpta	Wood turtle	E - WI
Clonophis kirtlandi	Kirtland's water snake	E - MI
Elaphe obsoleta	Black rat snake	T - MI
Elaphe vulpina gloydi	Eastern fox snake	T - MI
Emydoidea blandingi	Blanding's turtle	T - WI

continued

Table 4 (concluded)

Species		Status
Nerodia erythrogaster neglecta	Northern copperbelly	T - MI
Ophisaurus attenuatus	Glass lizard	T - WI
Regina septemvittata	Queen snake	E - WI
Sistrurus catenatus	Massasauga	E - WI
Terrapene carolina carolina	Eastern box turtle	T - MI
Terrapene ornata	Ornate box turtle	E - WI
Thamnophis proximus	Western ribbon snake	E - WI
Thamnophis sauritus	Northern ribbon snake	E - WI

[a] Data obtained from Michigan DNR (1979) and Wisconsin DNR (1979). Minnesota does not have an official state threatened or endangered species program. (Data from Minnesota Mutual Heritage Program.)

[b] T = threatened species status; E = endangered; MI = Michigan; WI = Wisconsin; MN = Minnesota.

[c] Occurs in waters within peatlands (Becker, 1976).

Smallmouth bass spawn, usually over a 6-10 day period, in late spring or early summer when water temperatures are between 60 and 65°F (Scott and Crossman, 1973). Smallmouths nest and deposit eggs in 2-20 feet of water on a sand, gravel, or rock substrate, usually near protective cover. The male guards the nest through the incubation and hatching process until fry reach about one inch in length (Mraz, 1964). Hatching success is reduced by sudden changes in water temperature, changes in water level, and increased siltation (Schneberger, 1972a).

Largemouth bass are distributed throughout the peatlands region, being more abundant in the southern portion of the area than toward the Canadian border (Eddy and Surber 1960). This species prefers shallow, weedy lakes and river backwaters, and often occupies wooded areas. The largemouth is usually found in association with soft, muddy substrates (Mraz et al., 1967).

Spawning occurs from May to July when water temperature is between 60-65°F (Mraz et al.,1967). Nests for egg deposition are placed in quiet water on a marl (calcium carbonate) or mud substrate near emergent vegetation. The male

largemouth, like the smallmouth bass, guards the nest. Egg survivorship is affected by water temperature, water level, and siltation (Scott and Crossman, 1973). Largemouth bass will not spawn at a pH of less than 5 and eggs will not hatch at a pH higher than 9.6 (Newburg, undated).

Both white and black crappies are common throughout the Upper Midwest peatlands region. Black crappies become more abundant than white crappies in the northern part of the region (Schneberger, 1972b). Both species of crappie are valued primarily as sport fish.

The white crappie has a distinct preference for turbid rivers, lakes, and sloughs and is often associated with basins having mud bottoms (Schneberger, 1972c). The black crappie, in contrast, inhabits clearer, cooler lakes and streams. The black crappie is intolerant of siltation and low oxygen concentration (Schneberger, 1972B).

Both white and black crappies spawn in May or June when water temperature reaches 64-68°F (Becker, 1976). Both species build nests for egg deposition in gravelly substrates, although the white crappie can also utilize other bottom types. Spawning sites are often close to vegetation, woody debris, and other structures (Scott and Crossman, 1973). The food of both species consists mainly of insects, crustaceans, and fish (Becker, 1976).

The orangespotted sunfish, warmouth, longear sunfish, and redear sunfish are uncommon, occurring only sporadically in the central and southern portions of the region (Eddy and Surber, 1960; Hubbs and Lagler, 1974). Furthermore, these species are neither sufficiently abundant nor large to be of significant recreational value. The longear sunfish has been awarded threatened status in Wisconsin (Wisconsin DNR, 1979).

The remaining representatives of the Centrarchidae are the green sunfish, bluegill, pumkinseed, and rock bass. The green sunfish is common in weedy, sluggish streams and in some lakes in the region, but seldom attains sizes acceptable to fishermen (Becker, 1976). Bluegill, pumkinseed, and rock bass are common to abundant in lakes and moderate sized streams throughout the Upper Midwest, with the exception of the Lake Superior drainage, where their occurrence is sporadic (Eddy and Underhill 1960; Hubbs and Lagler, 1974). These three species are valuable components of the sport fisheries in Minnesota, Michigan, and Wisconsin. Bluegills are frequently found in bog lakes and ponds (Becker, 1976).

The life histories of sunfish are basically similar. Spawning occurs from late spring through summer and a given female may spawn more than once a year. Eggs are deposited in sandy, gravelly, or muddy nests and are guarded by adult males (Hubbs and Lagler, 1974). Sunfish feed on a wide variety of aquatic and terrestrial organisms. All species consume aquatic insects and crustaceans. Pumkinseeds and redear sunfish often prefer snails, and green sunfish and rock bass frequently prey on small fish.

Salmonidae (Salmon Family)

The salmon family consists of a relatively large group of fishes including salmon, trout, and whitefishes. Several species of Salmonidae are restricted to the Great Lakes, and hence are unlikely to be affected by peat harvesting activities. The species occurring in inland waters of the peatlands region are the brook trout, brown trout, rainbow trout, lake trout, lake whitefish, and cisco.

The brook trout is the only trout native to streams of the peatlands region. The original distribution of brook trout in Minnesota included streams of the Lake Superior drainage and spring-fed streams along the Mississippi and St. Croix Rivers and in the southeastern portion of the state (Eddy and Surber, 1960). In Wisconsin and Michigan, the brook trout was common to most streams in the Great Lakes drainage and in many streams of the Mississippi drainage (Becker, 1976; Hubbs and Lagler, 1970). Due to habitat destruction and watershed clearing the brook trout's range has decreased (Brasch et al., 1962). This species' principal value is as a sport fish.

Brook trout are cold water fish, preferring clear, cold, headwater spring ponds and spring-fed streams (Brasch et al., 1962), although they also occur in suitably cold, well oxygenated lakes. Brook trout are most abundant in waters cooler than 68°F (MacKay, 1936b).

Spawning begins in late September and extends through November in this region. Eggs are deposited and covered in gravel riffles of spring-fed streams and in spring seepage areas of ponds (Brasch et al., 1962). Incubating eggs are susceptible to changes in water temperature, fluctuations in water levels, and siltation.

Brook trout are voracious feeders, consuming aquatic and terrestrial insects, crustaceans, and fish. Worms and molluscs are occasionally taken (Brasch et al., 1962).

Brook trout are intolerant of low oxygen concentrations and turbid conditions. This species is quite tolerant of low pH levels, and is occasionally found in streams draining peatlands (Robinson et al., 1976). Brook trout, however, avoid bog waters below pH 4.0 (Dunson and Martin, 1973).

The brown trout, a species native to Europe, is now represented by self sustaining populations in the Great Lakes watershed and in numerous streams throughout the Upper Midwest (Becker, 1976). The habitat requirements of the brown trout are not as restrictive as those of the brook trout. Therefore, brown trout have replaced brook trout in many regional streams that have become warmer or more turbid due to human activities. The principal value of the brown trout is its status as a sport fish.

Spawning takes place during October and November in streams, tributaries of lakes, and occasionally along shores of the Great Lakes. Eggs are deposited and covered in areas having a gravel, sand, or hard clay substrate

(Brynildson et al., 1977). Hatching occurs between 40 to 70 days depending on water temperature (Becker, 1976). Incubating eggs require water movement and are vulnerable to siltation and sudden changes in water levels (Brynildson et al., 1977). Brown trout feed on aquatic insects and larvae, crustaceans, and fish.

The rainbow trout has been introduced into the Great Lakes region from its native range along the northwestern coast of the United States. Through massive stocking efforts, rainbow trout are abundant in the Great Lakes and common in cool streams and lakes in the peatlands region. The primary value of this species is as a game fish (Becker, 1976).

Rainbow trout inhabit cool, turbulent streams and deeper lakes having excellent water quality (Scott and Crossman, 1973). This species is intolerant of conditions of high turbidity or siltation (Kwain, 1975). Adult rainbows can survive dissolved oxygen concentrations as low as 4-5 parts per million (ppm) and pH ranging from 5.8-9.5. Optimum reproductive success occurs at higher oxygen concentrations and moderate pH. No embryo survival takes place below pH 4.5 (Kwain, 1975).

Spawning occurs primarily from April to June although some varieties of rainbow trout spawn in the fall. Adults migrate from rivers into smaller tributaries or from lakes into inlet or outlet streams (Lindsey et al., 1959). Egg deposition usually takes place over a bed of fine gravel in a riffle above a pool (Scott and Crossman, 1973). Incubation requires 19 to 80 days depending on water temperature (Becker, 1976). During this period, siltation rate is the principal factor determining egg survival (MacKay, 1963a). Rainbow trout feed on aquatic insects and larvae, crustaceans, and small fish (Scott and Crossman, 1973).

Lake trout occur in some oligotrophic inland waters of northern Minnesota, Wisconsin, and Michigan. This species prefers cold, clean lakes with rocky shoals or ridges. The lake whitefish and cisco occur in similar habitats. All three species are intolerant of poor water quality and none are associated with peatland watercourses (Eddy and Surber, 1960).

Lake trout spawning occurs in October or November over rocky shoals or reefs. Lake whitefish and cisco spawn over rocky or gravelly shoals in November or December. Cisco and lake whitefish feed primarily on aquatic invertebrates, particularly Pontoporeia affinis and Mysis relicta in the Great Lakes. Lake trout also feed on invertebrates when young, but adults feed almost entirely on fish (Scott and Crossman, 1973).

Clupeidae (Herring Family)

The herring family is represented in the peatlands region by the gizzard shad and the alewife. The alewife is an introduced, anadronmous species which is found only in the Great Lakes proper. The gizzard shad is abundant throughout the Great Lakes region, particularly in the St. Croix, Minnesota, and Mississippi River drainages (Eddy and Surber, 1960). The principal value of these species lies in their utilization as forage by game fish.

Spawning activity occurs in spring and early summer. The alewife spawns in Great Lakes' streams and the gizzard shad spawns in more turbid sloughs, lakes and streams. Eggs are fertilized at the water's surface and become demersal and adhesive (Scott and Crossman, 1973). Incubating eggs of both species are relatively tolerant of water level fluctuations and siltation.

Hiodontidae (Mooneye Family)

This family is represented by two species in the peatlands region: the mooneye and the goldeye. Both species are common in the Upper Mississippi River and its tributaries (Eddy and Surber, 1960), but only the mooneye occurs in the Great Lakes drainage systems (Becker, 1976; Hubbs and Lagler, 1970). Both species are occasionally taken by anglers and also have some commercial value. Large quantities of goldeye have been commerically harvested from Minnesota's Red Lakes (Eddy and Surber, 1960). The goldeye has been given threatened status in Wisconsin (Wisconsin DNR, 1979).

Both of these species inhabit larger rivers and lakes, and reportedly prefer shallow, clear water (Becker, 1976). Little else is known of their life histories. These species may ascend tributary streams for spawning and their diets consist largely of insects, crustaceans, and small fish (Becker, 1976).

Umbridae (Mudminnow Family)

The central mudminnow is the only species of this family found in the Upper Midwest. This species is widely distributed, occuring in all parts of Minnesota, especially in the Red River and Lake Superior drainages, and throughout Wisconsin and Michigan (Eddy and Surber, 1960). The central mudminnow has no particular economic importance, but does serve as forage for predatory fishes.

The central mudminnow prefers muddy streams and pools having abundant aquatic vegetation (Scott and Crossman, 1973). The mudminnow may become abundant in bog habitats because of its ability to survive very low oxygen concentrations. The central mudminnow has been found in waters containing less than 1 ppm dissolved oxygen (Eddy and Underhill, 1974). This species is also able to burrow into the mud of evaporated or drained pools and thus survive periods of extremely low water levels (Eddy and Surber, 1963). The central mudminnow is often the only fish species present in areas of low oxygen concentrations and fluctuating water levels such as bogs (Eddy and Underhill, 1974).

Cyprinidae (Minnow Family)

The Cyprinidae are the largest family in the Upper Midwest peatlands region, being represented by over 40 species. Minnows are economically valuable by serving as forage for predacious game fish and being commercially cultured and marketed as bait fishes. Carp, the largest species in the family, is also harvested commercially and for sport. A number of species of the Cyprinidae are found on state lists of protected species. The gravel chub

and striped shiner are considered endangered species in Wisconsin (Wisconsin DNR, 1979). Wisconsin includes the Ozark minnow, pugnose shiner, pallid shiner, and speckled chub on its threatened species list. The bigeye chub, southern redbelly dace, redside dace, and silver shiner are considered threatened species in Michigan (Michigan DNR, 1979).

Cyprinids are widely distributed in the northern peatlands areas with the number of species found in a given vicinity decreasing as one progresses north in the region. (Hubbs and Lagler, 1974). The Cyprinidae are found in a variety of habitats ranging from fast moving streams with good water quality to sluggish, deoxygenated backwaters and lakes. Five species, the pearl dace, northern redbelly dace, finescale dace, longnose dace, blacknose dace, brassy minnow, and fathead minnow, are commonly found in peatland water (Becker, 1976).

Cyprinid species exhibit a variety of spawning habits. Some species build and guard nests, others bury their eggs in a gravel substrate, and some, such as the carp, broadcast their eggs randomly (Hubbs and Lagler, 1974). Minnows also feed on a variety of organisms including insects, worms, crustaceans, mollusks, and vegetation (Becker, 1976).

Ictaluridae (Catfish Family)

The Ictaluridae are represented in the Upper Midwest by the channel catfish, flathead catfish, bullheads (yellow, brown, and black), stonecat, tadpole madtom, slender madtom, brindled madtom, furious madtom, and northern madtom. The catfish and bullhead species are important to regional fisheries since they are sought by both sport and commerical fishermen. The madtoms offer no commercial or recreational value, but the slender madtom is classified as endangered in Wisconsin (Wisconsin DNR 1979) and the northern madtom is considered endangered in Michigan (Michigan DNR, 1979).

Channel catfish are common in the Mississippi River drainage, but do not occur above St. Anthony Falls on the Mississippi or above St. Croix Falls on the St. Croix River (Eddy and Surber, 1960). Channel catfish are also found in several major streams of the Lake Michigan drainage (Becker, 1976). The flathead catfish follows a similar distributional pattern, although it is less abundant than the channel catfish. Madtoms are found in a variety of habitats throughout the region, from fast flowing riffle areas of small streams to sluggish muddy areas with abundant vegetation. Bullhead species occur in virtually all habitat types, but reach maximum abundance in moderate to large streams and inland lakes. Bullheads are common, but not abundant, in peatland waters.

Catfish species exhibit similar spawning behavior. Eggs are deposited in nests or on rocks in late spring or early summer. Adult catfish and madtoms are intolerant of siltation and turbidity. Bullheads are extremely tolerant of adverse conditions including turbidity. Catfish eggs are vulnerable to excessive siltation and fluctuations in water levels (Hubbs and Lagler, 1974).

Percopsidae (Trout-perch family)

This family is represented by only one species: the trout-perch. The trout-perch is of little economic importance, but does serve as a food source for larger, piscivorous species. Trout-perch occur in many of the larger lakes and streams of the upper Midwest, including Lake Michigan. This species is abundant in the Upper Mississippi drainage, Red Lakes, Lake of the Woods, and Lake Winnebago (Becker, 1976; Magnuson and Smith, 1963).

The trout-perch prefers shallow and intermediate depths of larger lakes, is usually found over sand or gravel substrates, and avoids shallow, muddy bays (Becker, 1976). Spawning begins in May and can extend into August, and occurs in lakes or tributary streams over rock or sand substrates (House and Wells, 1973). Eggs are scattered over the bottom and no parental care is provided. Reproductive success is related to siltation rates and turbitidy. Trout-perch feed primarily on aquatic insects and crustaceans.

Cyprinodontidae (Killifish Family)

The Cyprinodontidae are represented by three species: the banded killifish, starhead topminnow, and blackstripe topminnow. The banded killifish is distributed throughout the Upper Midwest. The starhead topminnow and blackstripe topminnow occur sporadically in the southern portions of Wisconsin and Michigan (Becker, 1976) and neither species is reported from Minnesota (Eddy and Surber, 1960). The starhead topminnow has been given endangered status in Wisconsin (Wisconsin DNR, 1979). Killifish are occasionally used as bait and are preyed upon by piscivorous species.

The Cyprinodontidae prefer quiet, shallow waters of lakes and streams and are most abundant in areas of aquatic vegetation. Peatland waters are used as habitat by each of these species. Spawning occurs in late spring and summer in shallow water over submersed macrophytes or filamentous algae (Becker, 1976).

Gasterosteidae (Stickleback Family)

The Gasterosteidae are represented in the peatlands region by the brook stickleback. This species has little economic value but is used as forage by many piscivorous species. The brook stickleback inhabits small, spring-fed streams, spring holes, weedy lakes, and bog lakes (Hubbs and Lagler, 1974). The brook stickleback can tolerate habitats unsuitable for most other species and can become abundant in bog waters. Spawning occurs in spring and early summer for both species. The brook stickleback constructs nests of plant materials where the deposited eggs are guarded by adult males. This species feeds principally on aquatic insects and larvae of other fishes (Hubbs and Lagler, 1974).

Sciaenidae (Drum Family)

This family is represented by only one species: the freshwater drum. Although the freshwater drum is seldom sought by anglers, it is an important

commercial species, particularly in the navigation pools of the upper Mississippi River (Butler, 1965).

The freshwater drum is found throughout the Mississippi River drainage and the Great Lakes drainage, except in Lake Superior. In Minnesota, it is abundant in the Mississippi and its tributaries below St. Anthony Falls, in the St. Croix and its tributaries, and in Red Lakes (Eddy and Surber, 1960). Freshwater drum are particularly abundant in Lake Winnebago, Wisconsin (Becker, 1976).

Freshwater drum prefer sluggish, turbid streams and open water areas of large, warm lakes having mud bottoms. This species is tolerant of turbid conditions and fluctuations in water levels (Priegel, 1967). Spawning takes place in the pelagic zone of lakes where the buoyant eggs are transported by wind and current, hatching in about two days. Young drum feed chiefly on aquatic insects and small crustaceans while larger individuals consume greater amounts of snails and clams (Hubbs and Lagler, 1974).

Macroinvertebrates

Macroinvertebrate communities, like fisheries, tend to vary in species composition and structure in different peatland habitats. Acid bogs characteristically have poorly developed bottom fauna (Jewell and Brown, 1929). Welch (1952) tentatively concluded that representatives of Malacostraca, Oligochaeta, Mollusca (except Sphaeridae), Ephemeroptera, and Coelenterata are absent from acidic bog lakes lacking inlets and outlets. Coleoptera (beetles) may be abundant in bog lakes, however (Jewell and Brown, 1929; Hilsenhoff, personal communication). Peatland waters of more neutral pH, fens and transition areas, may possess more diverse and productive macroinvertebrate communities than bogs (Jewell and Brown, 1929). The following sections briefly discuss the distributions and life histories of major peatland macroinvertebrate taxa.

Insecta

Insects are the most diverse and abundant faunal phylum inhabiting peatlands. This is undoubtedly related to the fact that insects are the only invertebrates possessing wings, an adaptation which provides relatively great dispersal and survival ability (Borrer and DeLong, 1971). Much of the following information concerning the aquatic insect orders was obtained from Hilsenhoff (1975).

The Ephemeroptera are probably the most ubiquitous aquatic insect order, inhabiting a wide variety of habitats in the Upper Midwest. The Ephemeroptera (mayfiles) are a hemitabolous order, and include over 150 species in Wisconsin. Most species are univoltine, overwinter as nymphs, emerge in the spring, and are herbivores or detritivores. This group inhabits peatlands having near neutral pH.

The hemitabolous Odonata (dragonflies and damselflies) are represented by at least 127 species in Wisconsin. Most species inhabit littoral zones of

lentic waters. Nymphs are predaceous and have 10-12 instars. Eggs are laid in late spring and summer, and some species exhibit a winter diapause in the egg stage (Westfall, 1978).

The Hemiptera (bugs) include six aquatic and five semiaquatic families in Wisconsin, representing 105 species. Nearly all Hemiptera are bivoltine or multivioltine, overwinter as adults, and are predaceous, except for Corixidae which are herbivorous.

The Trichoptera (caddisflies) are represented by over 275 known species in Wisconsin, most of which are restricted to streams. Some species are quite tolerant of turbid conditions and high organic concentrations. In Illinois, Ross (1944) found Trichoptera to inhabit mainly streams and rivers with medium to slow current, frequently having heavy silt deposits.

Coleoptera (beetles) comprise the largest insect order, and are represented in Wisconsin by over 300 known aquatic or semiaquatic species in 11 families. Beetle pupae, however, are terrestrial or live in air filled cocoons. Life cycles, habitat preferences, feeding habits, and distributions vary widely from family to family. Dytiscidae, the most widely distributed family, are predaceous and inhabit lentic environments including ponds, puddles, marshes and swamps, and lake margins. Some Coleoptera, such as the Hydrophilidae, are able to survive in waters having low oxygen concentrations or depressed pH by living largely at the water-land interface. Coleoptera are the most abundant macroinvertebrates in acid bog lakes, sometimes reaching relatively high population densities (Jewell and Brown, 1929; Hilsenhoff, personal communication). Not only adult Coleoptera, but also larvae occur in bog lakes and Sphagnum mats (Jewell and Brown, 1979), which indicates that certain beetles are able to complete their entire life cycles in acid bog environments.

The Diptera (flies and midges) are a very large, holometabolous order containing over 98 genera in Wisconsin. Only 109 species are described in Wisconsin, and, in general, most species in the Upper Midwest are unknown or poorly described. Most aquatic Diptera have terrestrial adult stages and live in the water during the remainder of their life cycle. Diptera occur in every type of freshwater habitat, exhibit a wide range of food habits, and have a variable number of generations each year. The Chironomidae are the most widely distributed family and are found in most aquatic habitats. The most thoroughly studied family is the Culicidae because adults of some species feed on human blood and function as vectors of disease to man. Most Culicidae inhabit lentic environments including temporary ponds, marshes, snow-melt ponds, lake margins, and bogs.

The Plecoptera (stonefiles) are common throughout the Upper Midwest but are seldom abundant. Hilsenhoff (1975) reported 61 known species from Wisconsin, and a survey of Minnesota revealed 51 species (Harden and Mickel, 1952). Stonefly nymphs inhabit streams of all sizes, but characteristically require high dissolved oxygen concentrations.

Mollusca

The phylum Mollusca is represented in the peatlands region mainly by two classes, Pelecypoda (clams) and Gastropoda (snails). Species of Mollusca are restricted to waters having pH values above 5.7 (Jewell and Brown, 1929).

The most thoroughly studied group of Pelecypoda is the Unionidae (mussels). A survey of the Unionidae in Michigan produced 24 genera (Heard and Burch, 1966). Mathiak (1979) reported a total of 45 species of Unionidae from Wisconsin, 15 of which were found in the northern third of the state. Pelecypods are filter feeders, and as such are relatively intolerant of excessive siltation (Parmalee, 1967). A second family of Pelecypoda occurring in the peatlands area is the Sphaeridae (finger nail clams). The distribution of the Sphaeridae in North America is poorly known (Herrington, 1962), but the reports published by Herrington (1962) and Burch (1972) indicate that many species are very widely distributed.

The Gastropoda are divided into two main groups, the Prosobranchia, which possess a gill for respiration under water, and the Pulmonata, which have evolved a lung for obtaining air from the atmosphere (Clench, 1953). Watler and Burch (1957) reported 22 genera of Gastropoda in Michigan, many of which would be expected to also occur in Wisconsin and Minnesota.

Amphipoda

The Amphipoda (scuds) are chiefly marine but are represented in the Upper Midwest peatlands by two major groups. The Gammaridae are common in northern suface waters with the genus Gammarus by far the most abundant (Holsinger, 1976). A second major group associated with northern peatlands is the Tolitridae, which is represented by only one North American species, Hyalella azteca. In general, freshwater amphipods are cold-stenothermal, photonegative, and thigmotactic (Holsinger, 1976). Amphipods are often abundant in small streams, sloughs, swamps, seeps and springs. Few species inhabit large rivers or the open water of large lakes (Pennak, 1953). Most amphipods are shredding detritivores, usually found under gravel, leaves, or aquatic vegetation.

Decapoda

The most common of the Decopoda likely to occur in peatland waters are the Astacidae (crayfish). Few crayfish species occur in the Upper Midwest (Hobbs, 1976). Lippson (unpublished manuscript) reported four species of the genus Cambarus and four species of Orconectes to occur in Michigan. Greaser (1932) reported six crayfish species known from Wisconsin, all of the genus Cambarus. Bouchard (1978) described Cambarus species as typically inhabiting epigeon habitats such as seepage areas and lowlands.

The crayfish breeding season occurs during spring and summer in the Upper Midwest, and considerable temporal variation exists among species. Most species produce a single generation each year, and individual crayfish can live for three years (Hobbs, 1976). Crayfish are generally omnivorous, and their feeding habits include grazing, scavenging, filter feeding, and predation (Bouchard, 1978).

Branchiopoda

The Subclass Branchiopoda (Phylum Arthropoda, Class Crustacea) consists primarily of the order Cladocera (water fleas) in freshwater systems. The Cladocera, together with the Rotifera and the Copepoda are, in most cases the dominant major groups of freshwater zooplankton communites, being found in most habitat types (Brooks, 1959). The vital role of cladocerans as food for fish and macroinvertebrates, and their importance in the food chain of aquatic systems in general, is well known (Brooks and Dodson, 1965; Dodson, 1974; Lynch, 1979).

The various species of cladocerans generally exhibit a mild preference for certain habitats. The littoral zone of lakes harbors the greatest number of species, while the limnetic region is rich in numbers of organisms but poor in numbers of species (Brooks, 1959). Although most cladoceran families are planktonic, a notable exception is the Chydoridae, which are primarily substrate organisms (Freyer, 1968).

Cladoceran Feeding Habits

The Cladocera are filter feeders. Five pairs of ventral legs bearing numerous setae create a current of water through the body cavity. Food particles in the water are filtered out by the setae. Additionally, some forms such as the Chydoridae utilize a modified leg (postabdomen) to pick up larger food particles (Wetzel, 1975).

The major food source of cladocerans is algae. Odom (1971) points out that zooplankton pulses often immediately follow those of phytoplankton. However, nothing edible that enters the body cavity is rejected. Thus, organic detritus particles and bacteria are also sources of food for cladocerans. A few larger cladocerans, such as Polyphemus pediculus and Leptodora kindtii, are predacious and feed on protozoans, rotifers, and smaller crustaceans (Brooks, 1959). Recent evidence suggests at least minimal ability to selectively feed (Brooks and Dodson, 1965; Wetzel, 1975; Dodson et al, 1976). However, cladocerans generally feed on most food sources present.

Life History of Cladocera

The usual form of reproduction in the Cladocera is parthenogensis. During this process, females produce eggs which develop into more parthenogenetic females, without being fertilized. The number of eggs produced ranges from two in the Chydoridae to over twenty in the Daphnidae. These eggs are deposited in a brood chamber where they develop and hatch. Excluding Leptodora kindtii, whose eggs hatch as metanauplii, there are no larval forms of Cladocera (Brooks, 1959).

Parthenogensis will continue until conditions of stress occur. Stress conditions may result from a food shortage, drying up of a pond, or substantial temperature reduction. Under such conditions, some eggs will develop into males. Other eggs will develop that are haploid, thus requiring fertilization. Once fertilized, the carapace surrounding the brood chamber thickens and encloses around the eggs; this structure is called an ephippium.

The ephippium and the eggs are then shed from the body cavity. This structure as a unit is called a "resting egg" and lies dormant until conditions return to normal. The resting egg will always hatch a parthenogentic female (Brooks, 1959).

Seasonal Abundance of Cladocera

Seasonal abundance of the Cladocera is variable among species. However, a general trend is for low winter populations; this is often followed by an increase in spring due to rising temperatures and an increase in food supply from photosynthesis. Summer populations of cladocerans are somewhat unstable, largely due to shifts in available food and predation (Wetzel, 1975). Finally, abundance often increases in fall for many species.

Studies on seasonal occurrence of the cladoceran family Chydoridae have revealed trends similar to this general pattern. Whiteside (1974) and Williams (1978) state that most chydorid species peak in abundance during spring and fall, with a marked decrease in summer. Keen (1973) also found chydorid numbers to be low in summer, followed by a fall maximum and winter scarcity.

Duthie and Carter (1970) studied seasonal abundance of Bosmina longirostris (family Bosminidae). Their four year study also revealed consistently low abundances in summer. Furthermore, resting eggs were usually present in summer, indicating a period of stress. Bhajan and Hynes (1971) attributed this to higher water temperatures; their own experiments support this hypothesis.

Studies on the cladoceran family Daphnidae also revealed spring and fall peaks (Hall, 1964; Cummins et al., 1969). In both cases, however, summer minima were attributed to predation by the large cladoceran, Leptodora kindtii, and not to higher water temperatures.

Distributional Abundance in the Upper Midwest

Harmsworth (1968) notes the difficulty in setting up precise geographical distributions for cladocerans. Aside from taxonomic problems, this is primarily due to the cosmopolitan nature of many cladoceran species. Chydorus sphaericus, Acroperus harpae, and Alona affinis are examples of cosmopolitan cladocerans. Therefore, discussion of cladoceran distributions within the three-state area of Minnesota, Wisconsin, and Michigan is limited to generalities; not only because most cladocerans found there are also found elsewhere, but within the three-state area several species will exist in a variety of habitat types.

There are some cladocerans, however, which show greater abundances in northern states than elsewhere. De Costa (1964) conducted a study concerning the latitudinal distribution of the Chydoridae in the Mississippi Valley. He concluded that certain species could be classified as "northern species", due to a notable dominance in the northern portion of the study area. There were: Acroperus harpe, Alona quadrangularis, Alonella excisa, Eurycercus, and Graptoleberis testudinaria.

Various studies in the three-state area have consistently shown the cosmopolitan chydorid, Chydorus sphaericus, to be overwhelmingly dominant in a variety of lake types (De Costa, 1964; Keen, 1973; Whiteside, 1974). Although most chydorids inhabit the mud and submersed vegetation in the littoral zone, C. sphaericus is planktonic as well (Whiteside, 1974).

Other chydorids frequently encountered by researchers in the three-state area include: Alona affinis, A. barbulata, A. circumfibriata, Alonella nana, Camptocercus nec rectirostris, Kurzia latissima, Leydigia leydigi, Pleuroxus denticulatus, and P. procurvus (Quade, 1969; Keen, 1973; Whiteside, 1974; Williams, 1978).

Cladocerans of the family Daphnidae which have been described as common in the three-state area include: Ceriodaphnia lacustris, C. quadrangula, Daphnia galeata mendotae, D. pulex, D. pulicaria, D. retrocurva, and Scapholeberis kingi (Brooks, 1959; Brandlova et al, 1972; Torke, 1979).

Finally, other cladocerans common in the three-state area include: Bosmina longirostris (Bosminidae), Diaphanosoma leuchtenbergianum and Sida crystallina (Sididae), Holopedium gibberum (Holopedidae), Leptodora kindtii (Leptodoridae), Mocrothrix laticornis (Macrothricidae), and Polyphemus pediculus (Polyphemidae) (Brooks, 1959; Quade, 1969; Torke, 1979).

The cladocerans cited herein are all probably common to some extent in the three-state area. Based on the aforementioned adaptability of most cladocerans to a variety of habitat types, it is likely that the cladocerans will be found in water proximal to or draining the peatlands of the three-state area.

Cladocera Communites in Peatland Habitats

The presence of several common cladocerans has been noted in many studies on peatland water systems in the three state area (Welch, 1936; Welch, 1952; Gannon, personal communication). Not only are these cladocerans widely distributed but several appear to be highly tolerant of the wide range of physicochemical water systems found in peatlands (Welch, 1936). Welch (1936) and Bricker and Gannon (1976) found the following species of cladocerans to be present in peatlands of northern lower Michigan: Acroperus harpae, Bosmina longirostris, Chydorus sphaericus, Daphnia pulch, and Diaphanosoma leuchtenbergianum.

A few species of cladocerans appear to be endemic to peatland environments and are found in acidic waters (bogs). Two such organisms are the chydorids Alona rustica and Chydorus piger (Harmsworth, 1968; Quade, 1969). Additionally, Frey (personal communication) and Brooks (1959) cite Acantholeberis curvirastris (Family Macrothricidae) as characterisitic of bogs. Jewell and Brown (1929) found several A. curvirostris in a highly acidic sphagnum mat, in the absence of any other cladocerans.

The presence of these endemic and tolerant species is an important characteristic of the cladoceran community of bog waters. However, Welch (1936) contends that the peculiar nature of plankton assemblages withstanding the severe conditions of bog waters is constituted by the absence of many species rather than the presence of the more resistant forms.

COMPARISON OF PEAT MINING TECHNOLOGIES

Peat harvesting techniques differ fundamentally in the location and timing of peat dewatering. Natural peat deposits are greater than 80 percent water by volume (Boelter and Verry, 1977) and approximately 90 percent water by wet weight (U.S. Department of Energy, 1979). Most commercial utilization processes require peat having no more than 50 percent water content by weight. Therefore, the moisture content of natural peat must be reduced prior to use.

In sod peat, milled peat, and shaved peat mining, the peat is at least partially dewatered in situ before harvesting. Each of these methods utilizes harvesting machinery and it is necessary to drain the peatland sufficiently in order to support the heavy equipment. Dewatering is accomplished by means of a network of drainage ditches specially designed for each site and typically routed into nearby streams.

In the hydraulic (undrained) mining methods, the peat is dewatered after harvesting and excess water may be returned to the mine site. The mined peatland may or may not have a stream outlet to nearby surface waters. Each of these peat mining techniques is discussed in the following section.

DRAINED METHODS

Sod Peat Mining

The sod peat mining technique is used primarily in Ireland, Russia, Finland, and Germany. After the peatland has been surveyed, the drainage ditch network is designed specifically for the site. In Ireland, the drainage ditches for sod peat mines are spaced 750 to 820 feet apart with subdrains spaced 210 to 280 feet apart. Lateral ditches at right angles to the main ditches may be included at spacings of 100 to 160 feet (Midwest Research Institute, 1976).

Pre-mining preparation includes clearing large surface vegetation, and leveling the site. The functions of the initial drainage system include providing stable cutting faces for the specialized harvesting equipment and dry spreading grounds between the ditches (Midwest Research Institute, 1976). The initial ditches are relatively shallow, and are deepened and widened over time by the harvesting operations. Thus, the higher area between ditches available for spreading diminishes gradually.

In Russia and Ireland, peat is excavated along the ditch faces by a specialized bucket dredger. Excavated peat passes from the dredge, through a macerator, onto a spreader which deposits a ribbon of peat onto the peatland surface. Cutting disks follow the dredge and cut the extrusion into units of

manageable size about 14"x5"x5" (U.S. Department of Energy, 1979). These blocks of peat (sods) are left on the spreading ground until they are sufficiently dry for mechanized or manual stacking. The sods then remain stacked outdoors until moisture content is reduced to about 35 percent by weight (Midwest Research Institute, 1976; Bodle et al., 1978). Two (sometimes more) harvests of sod peat per year are usually possible in Ireland.

In Finland, the excavating dredge removes shallow horizontal surficial layers of peat, rather than vertical layers. Excavated peat is extruded through nozzles mounted behind the dredge. Other facets of the Finnish method are similar to the Russian and Irish systems.

Milled Peat Mining

The milled peat method is used principally in Ireland, Northern Europe, and Russia. The use of this technique has increased because it is typically more productive and less labor intensive than the sod peat method. The milled peat technique, however, requires the mining of a larger peatland area to produce a given quantity of peat than the sod peat method because peat is removed in very thin horizontal layers.

Pre-harvesting preparation is similar to that for sod peat mining. The peatland is surveyed and the drainage network is designed for each site. The drainage system for milled peat mining requires closer ditch spacing than the sod peat technique. Ditches are about 50 feet apart on the average, separated by fields where harvesting takes place (Midwest Research Institute, 1976).

Harvesting machinery traverses the prepared fields, scraping or milling a layer of peat one-half inch or less in depth. The harvesting machines pass the scraped peat over a rotating spiked drum for shredding, and return the shredded (milled) peat to the field for drying. The drying process can be accelerated by harrowing the shredded peat if necessary. When air dried to a moisture content of about 55 percent (Midwest Research Institute, 1976), the milled peat is collected in one of two ways.

The older method of collection, still used extensively in Ireland, consists of mechanically scraping the milled peat into ridges along the center of each harvesting field. The ridges of peat are then transferred to central piles for shipping or storage.

The newer collection method, used in Russia, Finland, Sweden, Canada and the United States is pneumatic harvesting. In the pneumatic technique, large vacuum harvesters cross the fields picking up a layer of dried peat particles about one-half inch in depth. A milling device is often towed behind the unit to prepare the next layer. Since only dry particles are gathered, the time from initial scraping and milling to collection is reduced from two or three days in the milled ridge method to one day. Vacuum harvesting can perform several operations at one time: milling, harrowing, harvesting, stockpiling, and transportation (Tibbets and Fraser, 1978). Twelve to 20 harvests per year are possible using the pneumatic harvesting technique.

Shaved Peat Mining

The shaved peat mining technique is essentially an American adaptation of the milled peat methods, substituting commercially available machinery for the highly specialized Soviet and European harvesting equipment. Most American peat harvesting operations are relatively small in scale compared to European mines. In the Upper Midwest, Sphagnum deposits (raised bogs) are mined for horticultural utilization and reed-sedge (lake filled) peat deposits are mined primarily for the production of potting soil. The locations of the major peat mines of the Upper Midwest are presented in Figure 5. In Russia and Northern Europe, peat is used both for horticultural products and as a fuel.

Shaved peat site preparation is similar to other drained peat mining methods. The peatland is first surveyed and the drainage ditch network planned. The site is then cleared of vegetation and leveled using bulldozers. Backhoes are typically used to install drainage ditches. This initial clearing and ditching usually takes place during winter in the Upper Midwest when the soil is frozen and able to support machinery.

When the peatland surface has drained sufficiently to support heavy equipment in the spring and summer (one or two years), woody debris is mechanically removed and the surface peat is scarified to promote further air and sun drying. Harvesting operations begin when the surface peat moisture content decreases to about 60 percent. As in the milled peat method, two harvesting techniques are used.

Traditional shaved peat mining employs bulldozers to scrape a thin layer of dried surface peat, which is pushed into windrows or piles. The peat is transported for processing or storage by draglines or front-end loaders and trucks. The scarification and harvesting procedure is repeated throughout the summer. Shaved peat mining may be used on reed-sedge and Sphagnum peats.

Pneumatic harvesting is also used in the United States. After scarification, vacuum harvesters, mounted on tractors or tracked platforms, traverse the peatland picking up only the dried surficial particles by suction. Vacuum harvesting in the Upper Midwest is used in larger commercial peat operations primarily on Sphagnum deposits, which are more valuable, have a smaller average particle size, and less woody debris than reed-sedge peat. Shaved peat mining may be alternated with vacuum harvesting on a given peat deposit.

UNDRAINED METHODS

Hydraulic Peat Mining

Hydraulic peat mining is still in the developmental stage (U.S. Department of Energy, 1979). There are several advantages theoretically implicit in hydraulic peat mining compared to drained methods. Hydraulic mining, by taking the entire harvestable depth of peat in a single pass rather than in shallow successive layers, can produce a greater quantity of peat in less time and the process does not depend on favorable weather.

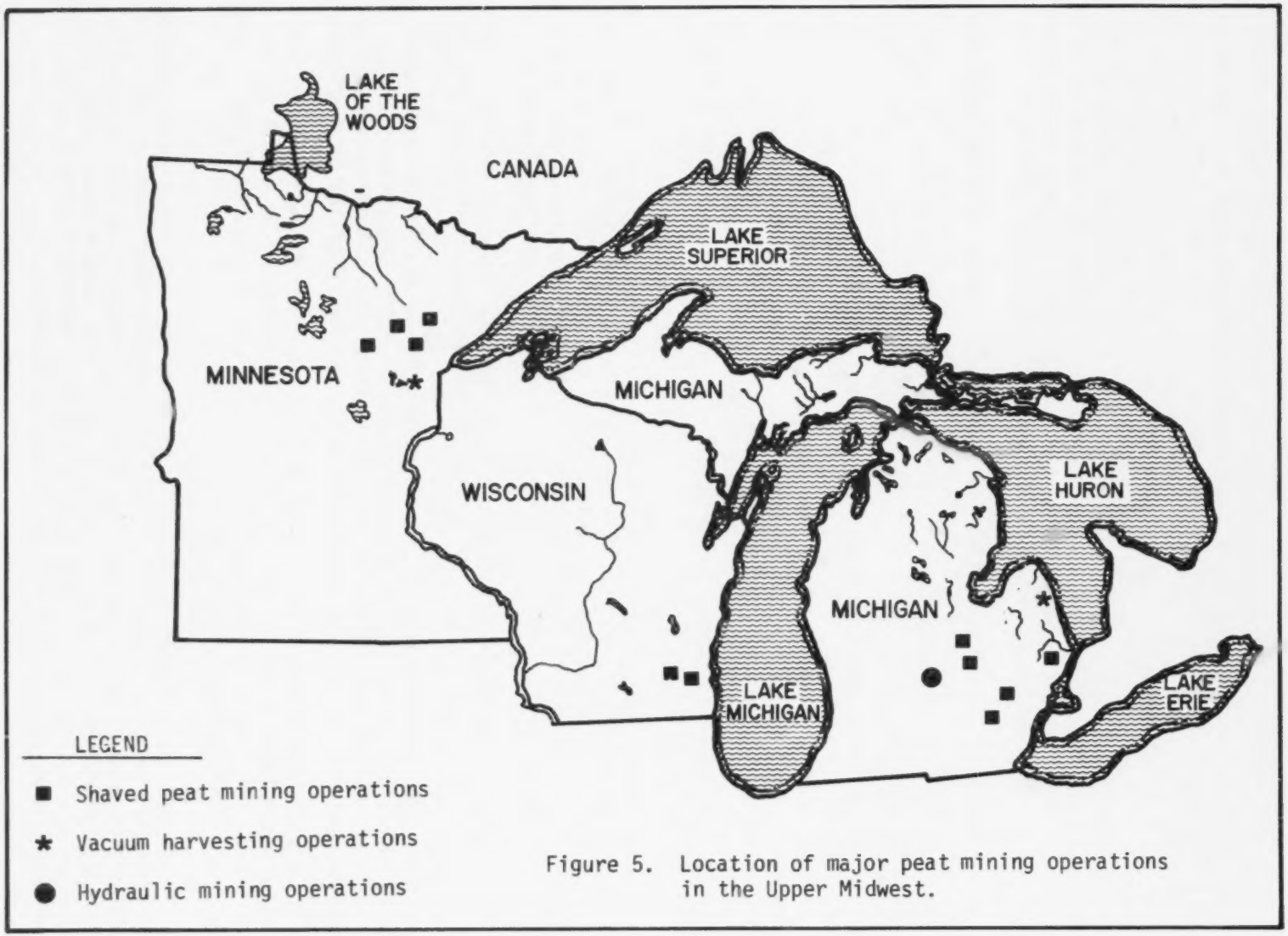

Figure 5. Location of major peat mining operations in the Upper Midwest.

Environmental benefits are also associated with this technique. A single-pass hydraulic peat mine would require only about five percent of the land area necessary for a milled peat mine of comparable production (Johnson et al., undated). Furthermore, hydraulic peat mining does not require peatland drainage. Water may be returned to the peatland rather than being routed directly into the regional surface water system.

In hydraulic peat mining, the site is cleared of woody vegetation as in other peat mining techniques. Peat is excavated from the bog or fen by means of a backhoe or dredge and is placed on a moving screen (U.S. Department of Energy, 1979). On the screen the peat is washed with jets of water to separate it from unusable material and to form a slurry of peat and water. The peat slurry is pumped to a dewatering station and excess water returned to the peatland. Since the excavated peatland fills with water, the dredge or backhoe is mounted on a barge. Active peat mines using this technique are located near East Lansing, Michigan and Vancouver, British Columbia, and at the U.S. Peat Corporation in South Carolina.

Variations on basic hydraulic mining are under refinement. A "hydro-peat" process is being studied in Russia which uses high pressure water jets to create a peat slurry (U.S. Department of Energy, 1979). The water jets, mounted on a floating platform, wash peat material away from roots and large debris, forming a pulpy mass. This mass is then pumped with water either to a drying field or to a mechanical dewatering station.

A barge mounted hydraulic dredge and cutting head has been tested in Minnesota (Johnson et al., 1979) that would directly excavate a slurry of peat from a water medium into a closed conduit system. Mechanical peat dewatering processes are being tested, and dewatering is considered the most difficult aspect of large scale hydraulic peat mining from an engineering standpoint (U.S. Department of Energy, 1979).

EFFECTS OF PEAT MINING ON AQUATIC ORGANISMS

Peat mining technologies can be divided into two categories with respect to potential effects on the aquatic environment: drained and undrained methods. Milled, sod, and shaved peat mining techniques require peatland drainage by means of a system of ditches connected with surface waters. Hydraulic peat mining does not require peatland drainage. Peat mining can have aquatic environmental effects of three kinds: (a) impacts on aquatic habitats within the disturbed peatland; (b) changes in the water quality of receiving waters; and (c) changes in water quantity in receiving waters.

Very few studies of the impacts of peat mining on water quality have been published. In their extensive literature review of peatland water resources, Clausen and Brooks (1980) found only two papers specific to peat mining and water quality. Peatlands have been studied with respect to certain components of mining, vegetation clearing, and drainage being examples. These studies and pertinent information from non-mining sources are discussed below.

PEAT MINING METHODS INVOLVING DRAINAGE

On-Site Effects

Peat mining techniques requiring drainage involve clearing peatland vegetation, draining the site, and harvesting a portion of the peat resource. Aquatic habitats existing in the peatland would be, at least temporarily, drained. If the mine is to be reclaimed for farming or forestry, the drainage could be considered permanent. Drained peat mines can be reclaimed as wetlands by backfilling the drainage ditch system. The degree to which previous aquatic habitats might recover is unknown and would vary from site to site. A drained peat mine can also be converted into a shallow lake by means of dikes. This has been done by Anderson Peat Company near Imlay City, Michigan and the lake (maximum depth of about 10 feet) supports northern pike, largemouth bass, and yellow perch.

Although the potential environmental changes due to drained peat mining are very similar in bogs and fens, the faunal groups impacted may differ. Bogs characteristically support low faunal abundance and have low species diversity. Zooplankton communities in bogs are depauperate due to low pH and the inavailability of calcium, but rare forms such as *Alona rustica* are specialized for such environments. Macroinvertebrate and fish populations in bogs are largely restricted to taxa having wide environmental tolerances such as Coleoptera, Sphaeridae, and the central mudminnow, bullhead, and brook stickleback.

Fens provide habitat for a more abundant and diverse assemblage of aquatic animals than acid bogs. Numerous fish species may be found in fens and peatland transition areas (Table 3). The most important function of these habitats with respect to man is probably their use as spawning and nursery areas by northern pike, muskellunge, and grass pickerel. In addition, the starhead topminnow, a Wisconsin endangered species, occupies peatlands in Southern Wisconsin and Southern Michigan. Therefore, aquatic habitats in fens and transition areas should be surveyed before being drained.

Off-Site Water Quality Effects
Alkalinity, pH, and Hardness

Drained peat mining techniques result in additional inputs of peatland waters (at least by volume drained) into downstream surface waters. Bog waters are low in pH, alkalinity, and hardness (Gorham, 1956; Verry 1975). High alkalinity values are typically associated with high buffering (ability to resist changes in pH due to additions of acid or base) and a high degree of hardness.

Most streams have alkalinities of less than 200 mg/l $CaCO_3$, whereas alkalinity in ground water can exceed 1000 mg/l (Clausen and Brooks, 1980). The waters supporting the most diverse aquatic communities have alkalinities of 100 to 120 mg/l $CaCO_3$ (McKee and Wolf, 1963). Peatland alkalinities range bewteen 26 and 82 mg/l for fens and approach zero in bogs (Clausen and Brooks, 1980). The term hardness refers to the concentration of salts in fresh waters. Calcium and magnesium combined with sulfates and chlorides account for the majority of permanent hardness in inland waters (Wetzel, 1975). Most lakes have calcium concentrations of greater than 10 mg/l. However, none of the 38 peatlands studied by Heinselman (1970) having pH less than 5.3 had over 10 mg/l dissolved calcium. A primary importance of dissolved calcium, magnesium, and bicarbonate is based on the relationship of buffering capacity increasing with increasing hardness. Similarly, most lakes have measured specific conductance measurements between 100-2,000 mhos/cm. Peatlands have low corrected conductivities ranging from 20-370 mhos/cm, and values from bogs are lower than from fens (Table 2). Thus, bog waters are of low pH and poorly buffered.

Although drainage or drainage and mining can increase the pH and hardness of waters draining bogs, the pH remains acid (pH 3.9-6.6) and hardness relatively low (Heikurainen, 1976; Ferda and Novak, 1976; Largin, 1976). Since the volume of water draining the mined peatland is, at least temporarily, greater than before drainage, utilization of drained mining techniques in bogs results in additional inputs of acidic water low in hardness to receiving systems. The water chemistries of fens and bog-fen transition areas are more variable than those of bogs. Waters draining these habitats, however, are generally harder and less acidic than bog waters. Therefore, the drainage effects of mining fens and peatland ecotones vary on a case by case basis.

The effects of increased inputs of acid water depend on the chemical nature of receiving waters. Well buffered, hardwater systems, typical of the Upper Midwest, are resistant to changes in pH. Crawford (1978) found that water from Lake of the Woods could receive at least an equal volume of bog water (pH 5.5) before pH changes occurred. Poorly buffered, softwater lakes are not resistant to changes in pH. Wright and Henriksen (1978) reported lowered pH in softwater lakes in Norway due to inputs of acidic precipitation.

The pH of water can affect the survival of individual species and the diversity of aquatic communites. Dunson and Martin (1973) found that brook trout did not survive in a peat bog drainage until dilution and buffering raised the pH above 4. Most gastropods and pelecypods (Hendry and Wright, 1976), and algae (McKee and Wolf, 1963) showed increased mortality at pH values below 5. Sutcliffe and Carrick (1973) reported that streams in the English Lake District having pH values of less than 5.7 had less diverse benthic macroinvertebrate faunas than more alkaline streams. Freshwater crustacean communities, particularly Cladocera and Copepoda, exhibit the relationship that species diversity decreases with decreasing pH (Fryer, 1980).

Macronutrients

The waters draining peatlands, especially bogs, contain appreciable quantities of phosphorus and nitrogen. Phosphorus and nitrogen have been studied extensively in limnology because of their effects on the rate of primary productivity and the eutrophication of aquatic systems. The term eutrophication is synonymous with increased growth rates of the aquatic biota in excess of the rate that would have occurred in the absence of pertubations to the system (Wetzel, 1975).

The concentration of nitrogen in fresh waters usually exceeds the phosphorus concentration by at least an order of magnitude. Therefore, the phosphorus supply is more easily exhausted and is most often the limiting nutrient in the majority of lake systems (Vollenweider, 1968). Nitrogen is second in importance only to phoshorus in limiting rates of primary productivity in aquatic systems (Wetzel, 1975).

Phosphorus concentrations in bogs are relatively high compared to lakes or fens. Bog waters are so deficient in mineral components such as bicarbonates and silicates, however, that nuisance algal blooms seldom occur (Ludwig et. al., 1980). Total phosphorus concentrations in peatland runoff waters are somewhat higher than those from other types of drainages in the eastern United States (Clausen and Brooks, 1980). Total nitrogen concentration in runoff waters from peatlands varies from about 0.3-2.0 mg/l, which is lower than nitrogen concentrations in streams draining a variety of eastern watershed types (Clausen and Brooks, 1980).

Preliminary results from an incomplete Minnesota Department of Natural Resources study indicate that total phosphorus and total nitrogen concentrations were higher in runoff from a peatland being mined by the milled method than from two undisturbed peatlands (Clausen, in preparation). In a survey in

Russia, Largin (1976) found increased concentrations of nitrate and nitrite in peatland drainages due to mining.

Numerous studies, including Edmondson (1961) and Vollenweider (1968) have reported the direct relationship between phosphorus loadings and eutrophication. Vollenweider (1968) also showed a direct correlation between high, sustained levels of algal productivity and average concentrations of organic and inorganic nitrogen.

Dissolved Oxygen

Peatland waters are typically low in dissolved oxygen. Oxygen is one of the fundamental parameters of the quality of water. Dissolved oxygen is required by all aquatic organisms possessing aerobic respiratory metabolisms. An oxygen concentration of about 5 ppm is adequate to sustain the life stages of most freshwater fish species (Hutchinson, 1967; Becker, 1976). Some species, such as the carp, central mudminnow, and northern pike are able to survive much lower concentrations.

The solubility of oxygen, and other gases, is affected nonlinearly by temperature and pressure (Mortimer, 1956). In addition, oxygen concentration affects the solubility of many inorganic nutrients (Hutchinson, 1957). Oxygen becomes dissolved in water mainly from the atmosphere and through photosynthesis of aquatic plants. Oxygen is consumed by biological respiration and by oxidation reactions.

Although peatland waters are usually low in dissolved oxygen, the direct effects on oxygen concentrations of receiving water should not be severe. In the mining process, peatland waters are drained by means of surface ditches, in which the water becomes oxygenated from the atmosphere. Natural streams draining anoxic bogs quickly become aerated (Verry, 1975). Oxygen levels in receiving waters may be affected, however, by the release of suspended solids.

Suspended Solids

The clearing, drainage, and mining of peatlands may result in increased suspended solids in runoff. Suspended solids occurring in fresh water include mineral particles, fine organic matter, phytoplankton, and zooplankton (Hutchinson, 1957). The suspended solids present in most peatland waters consist primarily of organic material (Wetzel, 1975). A related parameter, turbidity, is related to the concentrations of both suspended and dissolved substances, and is reported in terms of percent optical absorption as measured by a photometer. The concentration of suspended solids measured in waters draining several peatlands in Russia varied between 8 and 35 mg/l (Largin, 1976). The concentration of suspended sediment was higher in drainage from a mined peatland than from two undisturbed peatlands in Minnesota (Clausen, in preparation). An increase in suspended solids, especially organic materials, reduces the availability of oxygen through oxidation and decomposition (Hargrove, 1972).

High concentration of suspended solids are usually detrimental to fish and invertebrate populations. Excessive suspended sediment mechanically interferes with respiration and filter feeding (Cordone and Kelly, 1961), increases egg mortality in fish (Hansen, 1971), and decreases the availability of light for photosynthesis. Concentrations of suspended sediment exceeding 90 mg/l are considered detrimental to most fish species (McKee and Wolf, 1963).

Dissolved Organics and Color

The drainage of peatland waters colored by high concentrations of dissolved organic substances can affect receiving waters in several ways. Clausen (in preparation) reported that water draining from a mined peatland was darker in color than runoff from undisturbed peatlands. Since the runoff volume from a peatland undergoing artificial drainage is, at least temporarily, of higher volume than before drainage and of darker color, receiving waters should become more colored.

The concentration of organic substances dissolved in water has two primary ecological effects: changing patterns of light transmittance and chemically influencing the metabolism of the biota. Increasing the concentration of dissolved organic substances, particularly humic compounds, increases color and decreases light transmittance in water. In addition, the spectral characteristics of transmitted light are shifted. Light in the ultraviolet, blue, and green wavelengths is strongly absorbed by humic compounds. Therefore, transmittance of these wavelengths is sharply reduced with an increasing concentration of dissolved organics (James and Birge, 1938). By contrast, light absorption by suspended substances is not selective for specific wavelengths. Since even distilled water exhibits low transmittance in the red region of the spectrum, a high concentration of dissolved organic substances causes water to appear brown or black and sharply reduces the amount of light available for photosythesis.

Although the chemical basis is poorly understood, dissolved organic compounds also function to stimulate or retard the growth rate of the biota. Organic extracellular products have been shown to inhibit the growth of algae (Krauss, 1962; Hellebust, 1974). Other organic acids, particularly glycolic acid, stimulate algal growth (Wetzel, 1975).

The biotic effects of dissolved organic substances may be related to their effects on the availability of inorganic nutrients (Saunders, 1957). Humic compounds are strong agents of chelation and adsorption. Thus, the availability of nutrients can be controlled by the concentration and activity of organic substances (Shapiro, 1964; Wetzel, 1968). Since micronutients such as iron and aluminum can behave as growth inhibitors in the manner described by Barrows (1959), high concentrations of dissolved organic compounds may increase or decrease the growth rate of various aquatic plant species. Most lakes and streams have humic and fulvic acid (combined) concentrations of 1 to 10 mg/l (Steelink, 1977). The humic and fulvic acid concentrations for Russian fens varied from 16 to 45 mg/l and bog concentrations were from 85-140 mg/l (Largin, 1976).

Metals

Since peatland waters can contain relatively high concentrations of iron and since peat, particularly Sphagnum, tends to adsorb metals from the environment, concern has been expressed that the mining of peatlands would release metals into surface waters (Walter Butler Company, 1978; Crawford, 1978). The concentration of metals in fresh water can have important biological effects.

Iron and manganese are essential micronutrients of freshwater flora and fauna, and under certain circumstances may limit the rate of plant productivity (Wetzel, 1975). Other essential micronutrients include zinc, copper, cobalt,and molybdenum. Aluminum probably functions as a micronutrient at low concentrations (Bollard and Butler, 1966). The availability of iron and other metals depends on oxidation-reduction (redox) potential, which is related to pH and dissolved oxygen concentration. Diffusion, absorption, side reactions, and microbial metabolism complicate the behavior of metals in surface waters.

Iron occurs in extremely low concentrations in oxygenated waters. Ferrous iron becomes soluble under reducing conditions below pH 6 and ferric iron is soluble only below pH 3 (Hem, 1960). The concentration of iron in surface waters is usually less than 0.1 mg/l (Hem, 1970), but values approaching 5.0 mg/l have been reported from an acid bog (Ferda and Novak, 1976). Productive waters for fish usually contain less than 0.7 mg/l iron and the lethal limit for fish is about 50 mg/l (McKee and Wolf, 1963).

The other metallic micronutrients have differing but analogous patterns of solubility. Manganese is the most readily available micronutrient (Wetzel, 1975), but is rarely found in concentrations exceeding 1 mg/l (McKee and Wolf, 1963). Aluminum concentrations are generally less than 1.5 mg/l in peatland waters compared to a lethal limit of 5.0 mg/l for trout (Clausen and Brooks, 1980). The concentration of copper in Minnesota peatlands varied between 0.0 and 0.5 mg/l (Verry, 1975). Copper concentrations below 1.0 mg/l are not toxic to most fish species (McKee and Wolf, 1963). Zinc, an essential plant micronutrient, becomes toxic to fish at relatively low concentrations. This is especially true in soft waters where zinc concentrations of 0.01 to 1.00 mg/l can kill fish (McKee and Wolf, 1963). The waters of a Minnesota fen (relatively hard water) contained 0.28 mg/l zinc (Verry, 1975).

Some heavy metals, copper and zinc for example, operate as plant micronutrients at low concentrations. Other heavy metals, however, such as mercury, chromium, lead, and nickel appear to be toxic to aquatic life even in low concentrations. Environmentally persistent materials, including some heavy metals, tend to occur in higher concentrations in animals high in ecosystem trophic structure through the process termed food chain concentration (Woodwell, 1967). Thus fish may have mercury concentrations ten times higher than invertebrates which, in turn, may have mercury concentrations ten times higher than phytoplankton.

Both living and dead peat materials, especially Sphagnum species, adsorb heavy metals from the environment (Tolonen, 1976). Pakarinen and Tolonen (1976) reported concentrations of iron, manganese, zinc, copper, lead,

chromium, and nickel in Sphagnum deposits in Finland, Sweden, Germany, and Canada. Little is known of the concentrations of heavy metals in peatland surface waters and runoff. Clausen (in preparation) found no increase in heavy metal concentrations in runoff from a mined peatland, but did find increases in iron and aluminum concentrations. It should be noted, however, that peat which is mined for consumptive purposes is no longer available to adsorb and retain heavy metals from other environmental components.

Complex and Synergistic Effects

Clausen (in preparation) reported higher concentrations of phosphorus, nitrogen, suspended sediment, aluminum, iron, and color (presumably due to dissolved organic substances) in drainage from a peatland which was mined by the milled method compared to two undisturbed peatlands. Although the effects of each of these water quality parameters have been discussed, the effects of simultaneous increases in all of these parameters are not obvious. Increased concentrations of phosphorus and nitrogen act to increase primary productivity. At low concentrations, increasing amounts of iron and aluminum can increase productivity. At higher concentrations, however, these elements become toxic. Increasing concentrations of dissolved organic materials can stimulate or retard plant growth. The color added due to dissolved organics reduces light transmittance in water and hence the amount of light energy available for photosynthesis. Although suspended sediment from peatlands includes organic nutrients, increased turbidity reduces light transmissions.

The preceding combination of factors would probably increase the growth rate of some species and reduce the growth rate of others. Submerged macrophytes in relatively deep water, for example, are particularly sensitive to increased turbidity. Crawford (1978) tested the effects of additions of acid bog water (pH 5.5) to water from Lake of the Woods on the growth rate of two species of algae. In the first experiment bog water was added in increasing concentrations to cultures of Chlorococcus sp. in lake water. Small additions of bog water produced relatively large increases in the rate of algal photosynthesis. In a second experiment Crawford added centrifuged bog water to a culture of Anabaena sp. in lake water. No increase was found in the measured rate of photosynthesis for any concentration of bog water added. These results can be interpreted in two ways. Either centrifugation removed the nutrients from the bog water (in which case they were not in solution) or the physiological responses of Chlorococcus and Anabaena to bog water are significantly different.

Additional complex interactions among parameters are possible. Dissolved organic compounds can adsorb or chelate nitrogen, phosphorus, and metals. For example, Lundberg and Trihey (1975) found a rapid release of nitrogen and phosphorus to the water column immediately following the disturbance of the peat: water interface due to thinning in wild rice paddies on Minnesota peatlands, a 100 fold spike in soluble phosphorus and a three fold spike in nitrogen followed the thinnings. These increases disappeared within three to seven days, however, indicating rapid readsorption or chelation with organic substances.

Calcium and magnesium hardness can interact with a variety of other parameters. Additions of calcium have been found to reduce the toxicity of lead and zinc to the aquatic fauna (McKee and Wolf, 1963). Hendrey and Wright (1976) report that the effects of low pH on the aquatic biota are decreased if the total ion concentration, especially calcium and magnesium ions, in the water is increased.

The effects of variations in water quality parameters also interact with climate. Acid precipitation, which can approach pH 4 in the northern United States (International Association for Great Lakes Research, 1976), exacerbates the effects of increased inputs of acid drainage. Hagen and Langeland (1973) found that low springtime dissolved oxygen levels in Norwegian lakes forced adult fish to the surface where a combination of stratified waters of low pH and elevated lead and zinc concentrations from spring snowmelt runoff was often fatal.

Water Quantity Effects

Attributes of peatlands, particularly the water holding capacity of peat and the relatively level, water saturated topography of peat producing areas, influence regional hydrology. Fens, being supplied with ground water recharge, have different hydrological characteristics than perched bogs. Clausen and Brooks (1980) summarized the literature on peatland hydrology and detailed the differences in bog and fen hydrologic regimes.

The most important hydrologic charcteristics of peatlands pertaining to the aquatic fauna are: (a) water table height, which affects the water levels in peatland surface water habitats; and (b) the quantity and timing of runoff, which influences the water levels in receiving waters. In Minnesota bogs, water tables and runoff reach their maximum during spring due to snowmelt and rain (Bay, 1969; Verry and Boelter, 1975). Streamflow decreases through the summer and may cease altogether (Heinselman, 1963). Water discharge from fens is more uniform than from bogs because of the availability of ground water supplies. Maximum discharge is in spring and runoff decreases gradually throughout the remainder of the year (Verry and Boelter, 1975). Neither bogs nor fens regulate the annual distribution of runoff by storing water in wet times and releasing it in dry periods (Bay, 1969; Boelter and Verry, 1977).

The clearing, drainage, and mining of peatlands will affect the components of water balance: interception, evapotranspiration, storage, ground water level, and runoff. This analysis will primarily treat the effects on the components most important to the aquatic fauna, ground water levels, and runoff. A rigorous assessment of the effects of resource management alternatives on peatland water quantity, including a comparison of hydrologic methods appropriate for use in peatlands is presented by Clausen and Brooks (1980).

Clearing bogs and fens reduces interception and evapotranspiration. Most of the hydrologic impact of drained peat mining, however, is due to the drainage *per se* (Brooks and Predmore, 1978). The immediate and obvious effect of drainage is to lower the water table in the peatland (Olkowski and Olesinki, 1976; Clausen and Brooks, 1980). The effects on water table height

are greatest near the drainage ditches and the shorter the distance between ditches the lower the resulting water table (Ferda and Novak, 1976).

The lowering of a peatland's water table drains the aquatic habitats existing on the site and tends to promote subsidence (Brooks and Predmore, 1978). Subsidence increases the bulk density of peat, which reduces porosity and water retention capacity. Compaction of peat by harvesting machinery exacerbates these effects. Bogs are likely to exhibit greater subsidence than fens when mined (Brooks and Premore, 1978). The increase in bulk density and topographical changes accompanying subsidence tend to affect average and peak runoff flows (Clausen and Brooks, 1980).

The assessment of the effects of drainage on runoff is one of the most controversial aspects of peatland hydrology (Brooks and Predmore, 1978; Clausen and Brooks, 1980). Arguments have been stated that drainage either increases or decreases water storage capacity and hence reduces or increases the sensitivity to precipitation. Based on their extensive literature review of the subject, Clausen and Brooks (1980) report that, in general, peatland drainage increases storage capacity, reduces peak runoff flows, and increases minimum flows. Drainage also increases annual flows and distributes runoff more evenly throughout the year.

The volume and timing of runoff can affect the aquatic fauna in receiving waters. Several fish species utilized as game or commercially, including the walleye (Niemuth et. al., 1972) and northern pike (Szmania, 1973; Hubbs and Lagler, 1974) utilize peatland habitats and receiving water in peatland watersheds for spawning and nursery areas. High, stable springtime water levels are associated with reproductive success in these species. Low or falling water levels may prevent adults from reaching potential spawning areas or leave eggs and fry stranded (Threinen et al., 1966; Niemuth et al., 1972).

Variations in streamflow volume can affect the abundance and diversity of aquatic fauna. Evans (1978) found that the biomass of benthic macroinvertebrates decreased 76 percent and the number of macrobenthos species decreased about 25 percent in the Sturgeon River in Michigan's Upper Peninsula as a result of increased flow variability due to hydroelectric generation upstream. Geen (1974) reported, however, that decreases in the productivity of fisheries due to increased flow augmentation would significantly increase both macrobenthos and fish biomass due to an increase in minimum habitat area and diversity. Thus, it appears that if peak (spring) flows are sufficient, the increase in minimum flows and decrease in flow variability due to drained peat mining could have beneficial effects (in terms of water quantity) on the fauna of receiving waters.

UNDRAINED PEAT MINING METHODS

Whereas drained peat mining methods tend to convert a wetland ecosystem into a predominantly terrestrial system, hydraulic peat mining changes a wetland into a lake system. In the case of lake-filled peatlands, hydraulic mining reverts the wetlands to an earlier, open-water successional stage. Because peat itself is a major factor controlling peatland water chemistry,

the removal of peat from the water column affects the quality of the remaining water. Hydraulic peat mining also has different off-site effects on water quality and quantity. These impacts will vary depending on the amount of natural drainage from the mined peatland.

Water Quality Effects

The on-site effects on aquatic habitats would be similar for bogs and fens. In watercourses or fens which flood and are used for spawning and nursery areas, mining would have at least short term deleterious effects. The increased human and mechanical activity and noise and the increased concentration of suspended solids during the mining process would be unfavorable to fish spawning and nursery. Invertebrates, particularly mollusks, if present, would be negatively influenced by increased suspended solids. Long term effects, however, with proper mine design and reclamation, would be neutral or beneficial.

Bogs and acidic transition areas represent harsh aquatic environments with low species diversity and biological productivity. Most of the larger peatland associations such as the Lake Aggasiz associated peatlands in northern Minnesota are comprised, in part, of old lacustrine systems now raised or at least partially isolated from ground water. Mining these systems to replace the peat surface with open water could create shallow lakes similar in morphometry to the modern Red Lakes system, which has significant productivity and especially notable walleye and northern pike fisheries. The size of the new lakes would vary according to the pattern of peat deposits to be mined.

Several peatland developments on the Red Lake Indian Reservation have proven to be splendid northern pike fish rearing areas. The Ki-wo-say wildlife impoundment, created to service a complex of several hundred acres of wild rice paddies and for waterfowl, was developed on top of a large sapric peat deposit along the western edge of the Red Lake Indian Reservation. It provides the reservation with a reliable supply of yearling northern pike for sale to several states for fish stocking programs, especially in Pennsylvania and Ohio (Ludwig, personal communication).

The effects of hydraulic mining on the quality of receiving waters depends on whether or not the peatland to be mined has a drainage outlet. If the peatland has no outlet or if surface streams are rerouted around the mine site, off-site water quality impacts would be minimal. Discharge from the harvest pond would pass through the surrounding peat material which could act as a filtering mechanism for suspended solids and nutrients (Brooks and Predmore, 1978). The water leaving a hydraulic peat mine with no outlet should, therefore, be similar in quality to discharges naturally occurring before mining.

If the harvest pond has a direct outlet to surface waters, impacts on the quality of the receiving waters should be similar to those for drained peat mining techniques (Brooks and Predmore, 1978). Without mitigation, loadings of phosphorus, nitrogen, suspended sediment, dissolved organics, and color would probably increase to the connecting surface waters.

Effects on Water Quantity

The effects of hydraulic mining on water quantity relationships are not completely understood because of a lack of field data, but appear to be of lesser magnitude than the effects of drained mining methods. Vegetation removal and peat excavation result in reduced interception and increased water storage capacity (Brooks and Predmore, 1978). The formation of a harvest pond will result in reduced microrelief compared to the undisturbed peatland.

Evaporation from the pond's surface may or may not exceed the peatland's original rate of evapotranspiration. If the harvest pond possesses a direct outlet, maximum discharge from the site would increase due to the faster flow response of the pond surface versus the former peat surface (Brooks and Predmore, 1978). This quicker runoff response may result in a decrease in minimum discharge. Minimum discharge may also be reduced if evaporation significantly exceeds evapotranspiration.

If the harvest area does not have a direct outlet, the effects of undrained peat mining on discharge volumes would be slight. Maximum discharge would approximate high flows existing before mining because discharge would occur through the surrounding peat in a manner similar to undisturbed peatlands (Brooks and Predmore, 1978). Minimum discharge and total water yield from the site would be reduced if evaporation exceeds evapotranspiration.

LARGE SCALE PEAT MINING

Economic contraints associated with commercial utilization of peat as an energy source, either directly or converted to synthetic fuels, will necessitate harvesting very large quantities of peat. A 1,000 megawatt electric generating station, for example, would require about 3.5 million tons per year of dry peat for fuel (Bodle et al., 1978). Preliminary estimates reported by Punwani and Rader (1978) show that a 250,000 cubic foot per day SNG plant would use about 48,000 tons of dried peat (about 35 percent moisture) per day. Mining this amount of peat using milled or shaved peat technology would require a harvest area of about 400 square miles, which would be drained and devegetated for the life of the SNG plant (Johnson et al., 1979).

Mining such large tracts of peatland area by drained methods is probably not feasible for a variety of reasons. Sod peat mining is too labor intensive to be economically competitive. Milled and shaved peat technologies are also labor intensive and would require vehicular transport of harvested peat to the gas conversion plant site. The effects of draining such a large area would have much greater consequences on regional water quality and hydrology than existing small scale peat operations. Without mitigation, a drained peat mining operation of this size might result in eutrophication of the receiving waters due to inputs of nitrogen, phosphorus, and organic carbon. The receiving water might also exhibit reduced pH, increased color, and increased concentrations of suspended solids. Brooks and Predmore (1978) recommend against utilization of drained harvest methods on large tracts because of

probable increases in peak flow of runoff. The social and political reaction to a proposed mine of 400 square miles of bogs and fens in the Upper Midwest might not be favorable.

Single-pass hydraulic peat mining would require about five percent of the land area of the milled peat method, or a total of about 20 square miles for a 250,000 cubic foot per day SNG plant. Futhermore, hydraulic harvesting is less labor intensive and enables transport of peat from the mine to the processing plant via a pumped slurry. Therefore, large scale commercial peat mining in the Upper Midwest, such as the proposed Minnegasco peat gasification project, would almost certainly utilize hydraulic harvesting techniques.

The environmental effects of large scale hydraulic peat mining would be similar in kind to those previously discussed for existing, smaller hydraulic peat operations. In general, however, the larger the proposed excavation area, the higher the probability that significant surface waters would occur on the mine site. Peatland surface waters, particularly in fens, may provide valuable fish spawning and nursery habitat. This is especially true for minerotrophic fens rather than for bogs or acidic ecotone areas. These habitats would, at least temporarily, become unsuitable for fishes, and could be unfavorably altered (deepened) for the long term due to hydraulic mining.

Peatland watercourses could also be subject to impacts downstream. Mining through a stream would increase suspended sediment, nitrogen, phosphorus, and color concentrations. The water levels of streams could be affected by excavation upstream. Fluctuations in water levels in the stream channel may increase due to hydraulic mining. Peak levels may increase due to an increase in hydraulic conductivity upstream (lake surface versus peat surface) and minimum flows would decrease if evaporation from the new lake's surface exceeds the former evapotranspiration of the peatland. If the increase in flow fluctuations becomes sufficiently large, deleterious effects on the stream's fish and macroinvertebrate communites could result.

The habitat and water quality changes occurring due to large scale hydraulic peat mining may result in an aquatic environment that, in the long term, is more suitable for certain valuable fish species than the natural peatland habitat. The nature of the expected changes in water quality is exemplified in the preceding discussion of the Ki-wo-say wildlife impoundment and the wild rice developments studied by Lundberg and Trihey (1975). The specific environmental changes which occur, however, will depend largely on the actual mine design and reclamation objectives.

Large scale hydraulic peat mining could create a range of aquatic habitats ranging from one large lake to a series of smaller lakes and ponds. The sizes, shapes, depths, and substrate type (peat or mineral soil) of these lakes can be designed for utilization by specific fish species, within the constraints provided by the pattern of peat deposits and economic considerations. Although research is needed to determine optimal lake designs for given locations and target species, general relationships between lake morphometry and biotic productivity, species diversity, and spawning behavior of important fishes are well known.

Other factors being equal, a lake having a shallow average depth and hence a relatively high proportion of its total area as littoral zone, will exhibit a higher rate of primary productivity than a lake with steeper sides and greater average depth. This phenomenon is due to the high photosynthetic potential of aquatic macrophytes and associated epiphytes and the lack of photoinhibition in these species (Wetzel, 1975).

Lake morphometry has also been related to the abundance of faunal groups. Harmsworth and Whiteside (1968) found no positive relationship between the abundance of chydorids (Cladocera) and the rate of primary productivity, but suggested that chydorid abundance and diversity were dependent on the extent of the littoral zone. Many of the common benthic fauna which are extremely important in the diets of fish, decapods, amphipods (except Pontoporeia), mollusks, and insect larvae are specialized for littoral habitats (Ivlev, 1961; Straskraba, 1965).

It is apparent from the above paragraphs that in order to attain a diverse fauna and good fish production, the lakes created by large scale hydraulic peat mining should, as a general rule, have some littoral zone and not remain as steep-sided quarries. Ideally, the selected morphometry will accommodate the nutrient inputs for a given site: higher phosphorus and nitrogen inputs suggest somewhat steeper sides to discourage eutrophy. It may also be possible to incorporate beneficial features for valuable fishes in the new basins. Shallow marshy areas for northern pike and rocky or sandy shorelines for walleye could be considered if these were target species in the reclamation plan. Site-specific research will be necessary in order to evaluate alternative reclamation plans for a given location.

MITIGATION OF AQUATIC IMPACTS

It is clear from the preceding section that, although a range of aquatic impacts due to peat mining are possible, little data has been collected to document these impacts. The following discussion treats a variety of possible measures for mitigating the aquatic effects of harvesting peat. Several methods are presented that have been used successfully in coal and metallic mineral mining, but other techniques are suggested which would be unique to peat mining.

Since the degree of environmental impact due to traditional (drained) peat mining is inadequately known and large scale hydraulic peat mining remains hypothetical, widespread applicaton of a certain mitigative measure is probably not appropriate. Rather, the mitigation required at any given peat harvesting operation should be based on local environmental and engineering constraints and regional resource management goals. The development of certain environmental conditions, however, would probably result in unfavorable effects on many aquatic organisms and should be avoided:

(1) Effects to Avoid at the Mine Site

A. Destruction of threatened, endangered or important game species or their known habitats.

B. Significant increase in maximum runoff flow or decrease in minimum flow.

(2) Effects to Avoid in Receiving Waters

A. Lowering pH below 5.

B. Significantly increasing turbidity.

C. Lowering conductivity below 5 mhos.

D. Raising heavy metal concentrations to undesirable levels.

Specific mitigation methods for avoiding these impacts are discussed below for both drained and undrained peat mining techniques.

DRAINED PEAT HARVESTING OPERATION

Biological Survey

Sod peat, milled peat, and shaved peat harvesting technologies typically convert wetland habitat into a terrestrial system. Therefore, in order to avoid destruction of threatened, endangered, or game species or their habitats, a biological survey of the area proposed for mining may be necessary. Some peatlands afford negligible aquatic habitat for fish because of a lack of surface waters or the occurrence of harsh environmental conditions as in acid bogs. These peatlands would probably not require biological surveys. Other peatland types, however, provide habitat for fish and may require field sampling.

If a given peatland is found to be critical to some life stage of a protected species, the area in question may be declared unsuitable for mining. The major precedent for categorizing lands as unsuitable for mining is the Surface Mining Control and Reclamation Act of 1977. Alternatively, mining may proceed with mitigation for aquatic impacts. For example, if part of a fen provided spawning habitat for northern pike, water control structures could be built to hold water on the area during the spawning and nursery season while other portions of the mine site would be draining.

Site Erosion Control

Because of the fibrous nature of peat and the gentle terrain of peatlands, erosion from the mine site is of lesser magnitude than in surface mining for other minerals. Erosion control in drained peat mining occurs in two phases. During the active life of the mine, eroded material control would take place in association with the drainage channels (discussed in subsequent sections). After mining is completed, erosion control would be implemented in conjunction with the reclamation plan.

The establishment of vegetation is probably the most effective, least expensive, and widely applicable of erosion control techniques (U. S. Environmental Protection Agency, 1973). This technique is also consistent with economic incentives to reclaim peat mines for forestry or agriculture. Erosion control for peatlands reclaimed for fish or wild rice production is discussed below. Establishment of crops or trees on reclaimed peatlands may require additions of fertilizers and/or lime to the peat substrate (Reith et al., 1973; Adams et al, 1978). This may result in occasional inputs of these substances into drainage water.

Temporary erosion control can be provided by mulching, riprap, or surface scarification. Straw and wood fiber are the two most common mulches and are usually, like scarification, intended for temporary use in areas where permanent controls will be implemented later. Riprap is quite expensive for use over wide areas and is better suited for erosion control in channels.

Channel Protection and Runoff Control

Several techniques have been used to control the energy of water and soil erosion in channels. Methods include the placement of a protective liner such as riprap, matting, or rock to shield the natural substrate and reduce water velocity (U. S. Environmental Protection Agency, 1973). Energy dissipators such as cross channel dikes or rock barriers are used to reduce water velocity. Flumes may be used for erosion prevention (Mills et al., 1972). Extensive channel protection measures will not likely be necessary at most peat mines because of the relatively flat topography. The use of control structure such as flumes should be minimized because of their resistance to biotic colonization.

Water Diversion

Diversion is the process of collecting and/or channeling water away from erodible or pollution forming materials. The channels are designed to accomodate projected peak flows, calculated from local historical weather data and topography. Channel protection measures can be taken if necessary. If a watercourse intersected an area proposed for drained peat mining and unmitigated mining would cause unacceptable alteration of water quality, diversion might represent a cost effective alternative to water treatment.

Settling

Settling is used to reduce the concentration of suspended solids in an effluent. The ability of water to carry suspended solids is directly related to its velocity, hence particles tend to settle out of suspension as water velocity decreases. Ponds are often used as settling basins in the mining industry. The size and flow rate of the settling pond determine its effectiveness in treating a given sediment load (U. S. Environmental Protection Agency, 1973). Clausen & Brooks (1980) summarize information on the settling rates of peat.

The suspended sediment concentration from peat mining may not require settling ponds for effective treatment. Any structure which slows water velocity sufficently will increase settling of suspended matter. Water distribution systems will reduce water velocity, causing a reduction in suspended solids. Clausen and Brooks (1980) note that outlet ditches could be meandered and the final outlet water could be allowed to filter through unditched peat rather than connecting directly to a stream.

Allowing discharge water to be distributed to unditched peat may produce water quality benefits other than reduction of suspended solids. Peat has high cation exchange capacity and high sorption and chelation properties, which cause peat to act as a sink for metals and nutrients. It may be possible to achieve reductions in heavy metal, phosphorus, and nitrogen concentrations in mine effluents by means of a final peat filter. Another interesting alternative is the possibility of constructing peat-lined settling ponds. This might enable settling and heavy metal and nutrient reduction in a single step, and the degree of treatment could possibly be optimized by manipulating basin residence time.

Neutralization Reactions

In cases where mine effluents are excessively acid or receiving waters are unbuffered, some degree of acid neutralization may be necessary. Although almost any alkaline material can be used to neutralize acidity, lime, hydrated lime, and limestone are most commonly used because of cost effectiveness.

Acid neutralization may provide additional water treatment benefits. The addition of lime or limestone can increase the conductivity and buffering capacity of water. The neutralization of acidic water can reduce concentrations of heavy metals. Ferric iron, aluminum, and lead tend to precipitate as insoluble hydroxides in the range of pH 6.3 (U. S. Environmental Protection Agency, 1973). Limestone, however, is much less effective than lime in treating acid drainage containing ferrous iron due to the occurrence of interfering side reactions. Hasler et al. (1951) reduced the color of two brown-water bog lakes in Wisconsin with additions of lime, which precipitated colloidial organic material.

UNDRAINED PEAT HARVESTING OPERATIONS

Undrained hydraulic peat mining may represent a new magnitude of scale in peat mining. Due to the potentially large mining areas, biological surveys would likely be necessary to determine whether threatened, endangered, or game species inhabit the mine site.

The volume of water discharged from a hydraulic peat mine could vary from practically zero in a basin having no outlet to moderate volumes in a basin having a surface outlet. It may be feasible to regulate the volume of the outlet by means of control structures.

In cases where a watercourse intersects an area proposed for undrained peat mining, it may be cost effective to minimize downstream impacts by diverting the stream around the mine site, thus creating a mining basin with no outlet. In other cases, it may prove more effective to mine the site without water diversion, proceeding from upstream to downstream. In this technique, the peat lying between the area of active mining and the final outlet can act to trap sediment, metals, and nutrients. Water treatment, if necessary, would occur in the vicinity of the outlet.

Hydraulic peat mines lacking surface outlets would probably require little or no water treatment. The degree of treatment necessary for discharges from hydraulic mines having outlets is unknown. Channel protection and runoff control, settling, and neutralization are possible, but application will depend on conditions at each specific site. During the active life of the mine, sediment screens (commonly used in dredging operations) located near the outlet represent an alternative to settling suspended solids. A conceptualized large scale, hydraulic peat mine showing possible mitigative measures is diagramed in Figure 6.

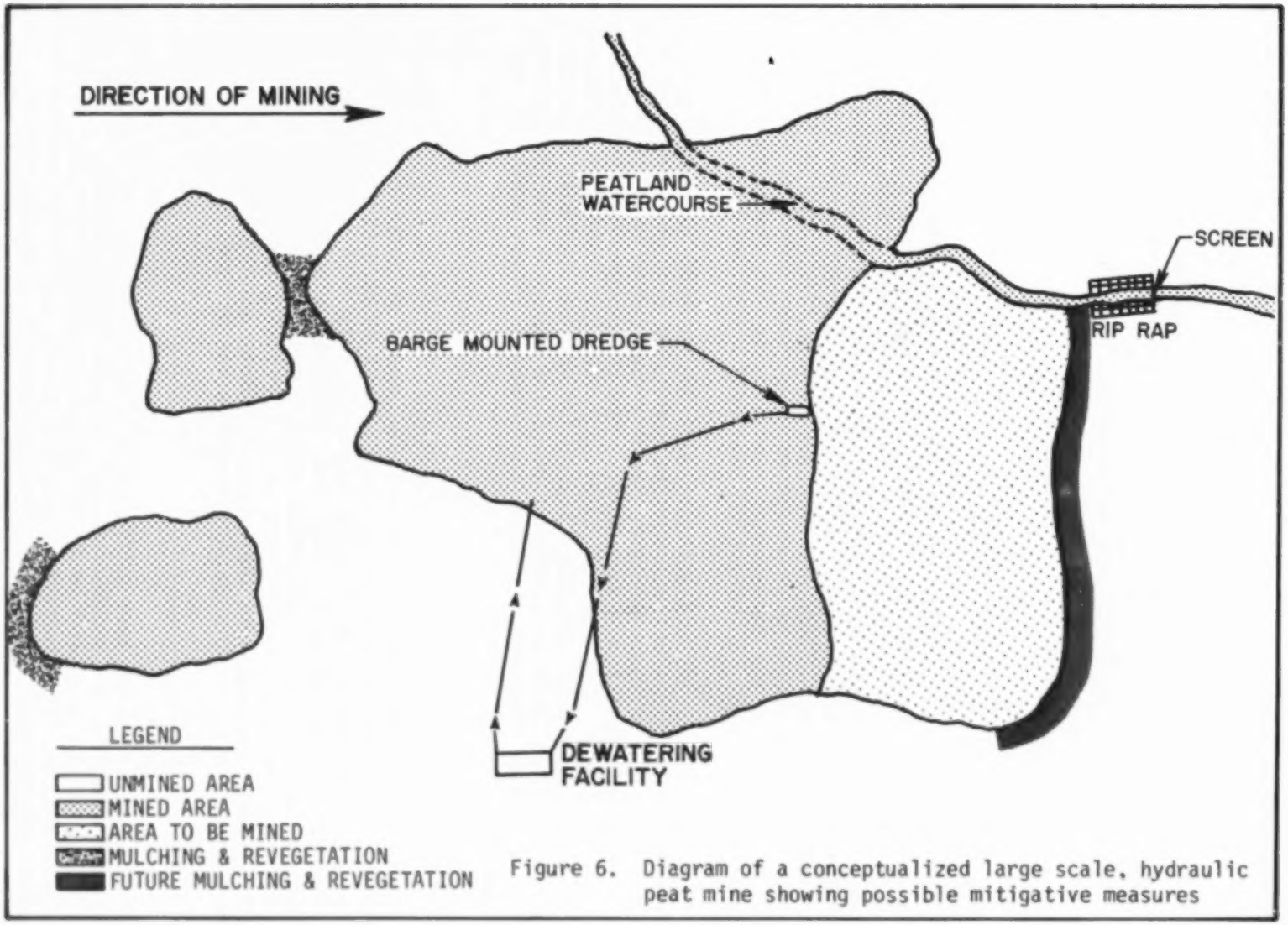

Figure 6. Diagram of a conceptualized large scale, hydraulic peat mine showing possible mitigative measures

DATA GAPS

FAUNAL SURVEYS

Perusal of the literature on the ecology of peatlands shows that most studies have been concerned with terrestrial ecology, particularly vegetation. Most of the aquatic studies conducted in peatlands have focused on acid bog waters. These are studies of depauperate faunal communites which include specialized forms such as Alona rustica and very tolerant species typified by the central mudminnow. There have been few aquatic faunal studies of fens and fenlike transition areas, which are potentially richer habitats. This situation is exacerbated by the apparent confusion in the fisheries literature between fens and bogs, i.e. almost all peatlands are called bogs.

The two classes of habitat that could be impacted by peat mining are waters within peatlands and watercourses downstream from peatlands. In order to assess impacts to these habitats, faunal surveys, especially for threatened and endangered species are necessary. Prompt surveys for threatened and endangered species are also of value to potential developers because of federal and state legal considerations. Furthermore, systematic surveys of peatlands aquatic fauna on a regional basis are needed to provide the comparative data base necessary in order to recognize unique peatlands species assemblages.

MINE DESIGN

Details of actual mine designs will be needed in order to assess local impacts. For example, will water level control be necessary? Will excess water from a dewatering facility be returned to the mine site? What is the pattern of peat excavations? Will the result be a patchy series of small lakes separated by peat islands which may be subject to wind and wave erosion? Or will the result be large lakes with potentially different hydrological responses than the peatlands they replace? These questions must be answered before site-specific environmental assessments can be made.

HYDROLOGY

Hydrologists do not have sufficient data to predict the effects of large scale peat mining on groundwater and surface water regimes. Important questions remain: what will be the effects on adjacent groundwater supplies?, and what will be the effects on maximum, minimum, and average surface flows? Studies are currently being conducted in Minnesota that will address these questions for small excavations (less than one acre). Hydrological studies of much larger peatland excavations are needed.

WATER QUALITY

The degree to which hydraulic peat mining will release acidity, macronutrients, suspended solids, metals, and dissolved organic material into surface waters is unknown. A study is being conducted in Minnesota which compares runoff from disturbed and undisturbed peatlands for a wide variety of chemical parameters. This will represent the most complete study of peatland water chemistry available. What is needed for impact assessment, however, is chemical monitoring of runoff before, during, and after hydraulic mining in a given peatland.

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This study reviews the literature pertinent to peatlands and peat mining in order to determine the effects of peat mining on aquatic animal life. The paper proposes to describe the peatland aquatic habitat and fauna, to compare existing and proposed peat mining techniques in light of peat mining possibilities for alternate energy sources, to suggest possible mitigation of undesirable effects and to identify important data gaps in the literature.

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